Appendix B. Assessing Right Whale Entanglement Risk through In Situ, Gear-Whale Flipper Interaction Experiments, *UNH and Blue Water Concepts*

Assessing Right Whale Entanglement Risk through In Situ, Gear-Whale Flipper Interaction Experiments

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Introduction

Management of marine mammal populations falls within the jurisdiction of the National Marine Fisheries Service (NMFS) under the Marine Mammal Protection Act (MMPA) of 1972 and, for some species, under the Endangered Species Act (ESA) of 1973. Entanglements in fishing gear have been identified as a significant factor impeding the recovery of endangered large whale populations, particularly the North Atlantic right whale, *Eubalaena glacialis*. The right whale is critically endangered, and anthropogenic mortality from entanglements and ship strikes threaten its survival (Caswell et al, 1999; Fujiwara and Caswell, 2001; Kraus et al, 2005).

The most recent report from NMFS on serious injury and mortality of baleen whales in coastal waters of the Gulf of Mexico (east coast), US east coast and adjacent Canadian Maritimes indicated that from 2003-2007 there have been 20 confirmed entanglement events of North Atlantic right whales, one categorized as a serious injury and a further three resulting in mortality. Scarring data shows that a high percentage of right whales get entangled every year and roughly 73% of individuals alive in 2004 showed evidence of having become entangled at least once (Knowlton et al., 2008). Of serious concern is that from 1980-2004 the severity of scarring from ropes (including the deepness of flesh cuts and wrap tightness) has increased (Knowlton et al. 2007, 2008). Although NMFS and the States of Massachusetts and Maine have made progress in addressing some of the fishery entanglement issues (Johnson et al, 2007), and a number of new ideas have emerged that are being tested (Werner et al, 2006), the continued mortality and serious injuries of right whales show that more work is needed. One of the problems in addressing the gear interactions with endangered whales is the difficulty in conducting meaningful field tests on fishing gear with the animals. Because entanglements are extremely rare for any given location or fisherman, testing the entanglement effects of an innovative fishing gear in a realistic manner with sufficient statistical power is not feasible. Thus the ALWTRT has attempted to move toward mitigation measures that intuitively reduce risk to large whales, but are not supported by concrete evidence of their efficacy. In the face of this conundrum, we attempted to address one specific problem – what happens when a whale's flipper encounters a line in the water column? Defining the characteristics of this encounter may help to develop buoys and or lines that will do less damage to whales and are less likely to entangle them.

Objectives

The goal of this work was to develop a full size North Atlantic Right Whale (NARW) flipper model and a support system to enable full scale testing of the

flipper and gear interactions. There were two basic tasks associated with this work:

1. Evaluation of flipper operation on the test vessel *Jesse B* including speed vs. drag force, camera placements and data acquisition.
2. Perform line-flipper interaction experiments for typically used line, "weak line" and Time tension line cutters (TTLCs), with all testing done in the two to three knot range, considered typical swimming speeds for a right whale.

Methods

The flipper model was built under an earlier contract, and a description can be found in that report (Baldwin and Landino, 2007). Essentially, the model was constructed from measurements taken of a stranded adult right whale (RW# 1004, "Stumpy") using boat construction materials and methods. The flipper was weighted with concrete to recreate the weight and mass of the original, articulated and attached to full size model of the body section, and covered in a combination of plastic and hard rubber layers to mimic the surface of a whale (Figure 1).

Figure 1. Completed flipper-whale body section while being weighed in air and water at UNH Chase OE Lab.

Evaluation of Flipper Operation

The vessel used for testing flipper-gear interaction was the 34-foot refitted fishing vessel the *Jesse B*. The development and evaluation of the flipper deployment with the *Jesse B* first involved coming up with a relatively quick method for attaching and removing the flipper from the vessel (Figure 2). This was important as there was always a timing conflict with the tides at either end of the testing runs. Several preliminary tests were run to understand the handling of the *Jesse B* when the flipper was attached to ensure the tests could be carried out effectively and within the constraints imposed by tidal cycles. It was also necessary to verify that the vessel could achive the desired speed of 2-3 knots with the flipper deployed. Finally, preliminary deployments were used to develop the expertise to handle the boat with the flipper fully deployed, and gain the confidence needed to perform the tests.

Figure 2. The flipper deployment frame mounted on the *Jesse B*. The vertical frame was secured with a pin at the end of the bottom-mounted horizontal bar which dropped into a socket attached to the keel.

After the boat handling questions were solved, the focus turned to the instrumentation. Two instruments were deployed for data acquisition. A load cell was installed above the water line between the hauler and the supporting cable. This load cell provided data concerning the loads on the system due to fluid drag, gear encounters, and, indirectly, gear behavior on the bottom. A single video camera was installed at a strategic location for observing and recording the gear/line-flipper interactions. Both instruments were installed before the initial

sea trials. The load cell and the camera were set up to record data and imagery on the same PC to time sync the data (Figure 3).

Figure 3. Flipper model deployment configuration, including locations of the load cell, camera and flipper. Also visible is the side-mounted flipper frame, which could be lowered or raised as needed.

The system evaluation was performed between two and three knots. The drag on the system was recorded with the load cell and was between 150lbs and 300lbs depending upon speed and articulation angle. Prior to each experimental trial, the starting drag forces were recorded due to the flipper without any other external loads. One operational concern was that large drag forces could adversely affect the steerage of the *Jesse B* forcing her to pull to one side. During initial trials the structural robustness of the system was tested – both the flipper and attachment bracket performed as expected. The camera was recording during the initial testing to verify the performance of the data acquisition. The PC recorded both the video signal and the load cell signal simultaneously.

Line-Flipper Interaction Experiments

These experiments were conducted in the Piscataqua River, NW of Frankfurt Island. This location was selected due to the availability of different bottom types in close proximity. The goal was to approximate actual fishing conditions, and to record and observe the vertical line-flipper interaction as the line encountered the model flipper.

A vertical line was as attached to the end line of a five trap trawl. An end line was attached to each end of the trawl for safety. The gear was deployed as it would be in an active lobster fishery. The traps provided 'realistic' bottom resistance conditions.

The experiments were conducted with different geometric parameters defined in Figure 4. The angle θ represented the front to back articulation of the flipper relative to the *whale body*. The distance, *d*, was the distance from the *whale body* to the point of contact along the flipper. Measurement of this distance was facilitated by scaled markings on the leading edge of the flipper. The angle θ was set before the testing runs commenced. This parameter along with vessel speed were the easiest variables to control and define. The distance *d* occasionally required some external control to guide the line to the proper location along the flipper. The flipper was deployed on the starboard side of the *Jesse B*; hence the gear was always kept to the starboard (Figure 3) to ensure an interaction of line and flipper.

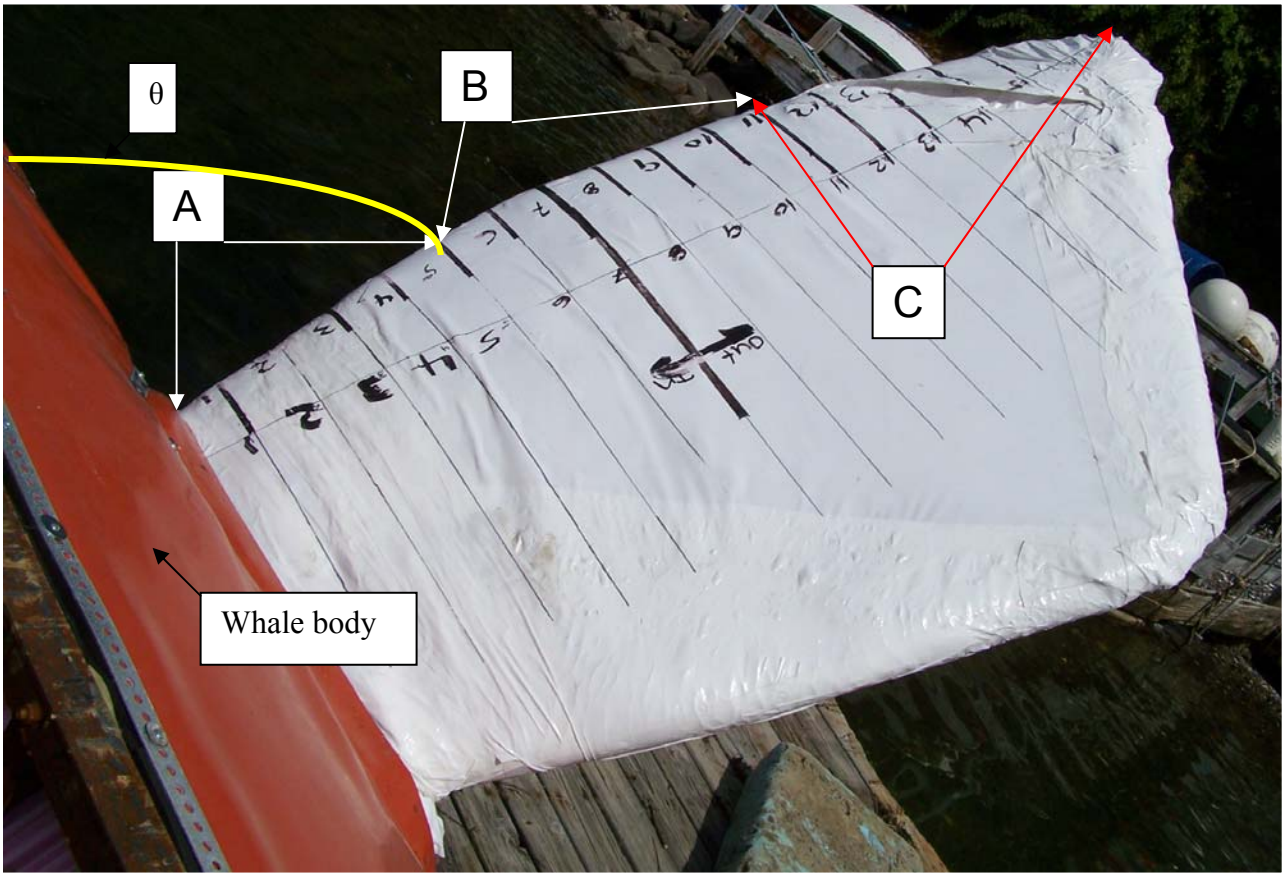

Figure 4. This photograph shows the *d* parameter zones, A, B, and C, used in the line-flipper testing. The zones were defined specifically as: A: 0-50 cm, B: 50-110 cm, C:110-176cm The yellow arc shows the angle θ between the outer edge of the flipper and the 'body'.

There were three possible flipper angle settings: 1) an acute angle between the flipper and *whale body* (as if the whale moved its flipper forward), 2) a normal angle (approximately 90 degrees) and, 3) an oblique angle (flipper moved back along the body). These angles reflected observations of biologists in the field. Whales move their flippers forward when they are about to dive. The right angle position represents a whale resting or travelling slowly at the surface, and the oblique angles are probably more common during diving and or ascents. The exact θ values were arbitrarily set and constrained by the fabrication restrictions when the system was finally assembled. Although whale flippers can also move along a vertical directional plane (that is, by altering the angle between the lower surface of the flipper and the main whale body), vertical flipper position influences only the probability of a flipper hitting the rope but not the dynamics of the encounter that are the focus of this study. If a whale's flippers are completely vertical, and the whale swims upright in the water, the risk of entanglement with vertical lines on a flipper would be nearly zero; if a whale's flippers are held at right angles (on a vertical scale) to the body, the chances of the flipper encountering a vertical line is substantially higher if the whale swims near one. However, because this study was designed to evaluate the duration and potential release times of ropes that hit a flipper, the probability of entanglement is not relevant and thus neither is vertical flipper position.

The distance *d* had three zones based on the shape of the leading edge of the flipper. The flipper had a local apex at approximately 75 cm from the *whale body*. It was relatively flat in the vicinity of this apex and then dropped off to the tip (Figure 5). The three zones represented the distance from the whale body, along the leading edge of the flipper. Zone A (0-50 cm) was the zone nearest to the body, where the leading edge inflects toward the body when the flipper was at right angles. Zone B (50-110 cm) included the local apex in the flipper shape (Figure 5). Zone C (100-176 cm) inflected away from the body. The testing was designed to observe line flipper interactions in all three zones indicated in Figure 4. The challenge was to replicate the line flipper interactions in each of the three zones, especially in Zone B where the local apex existed.

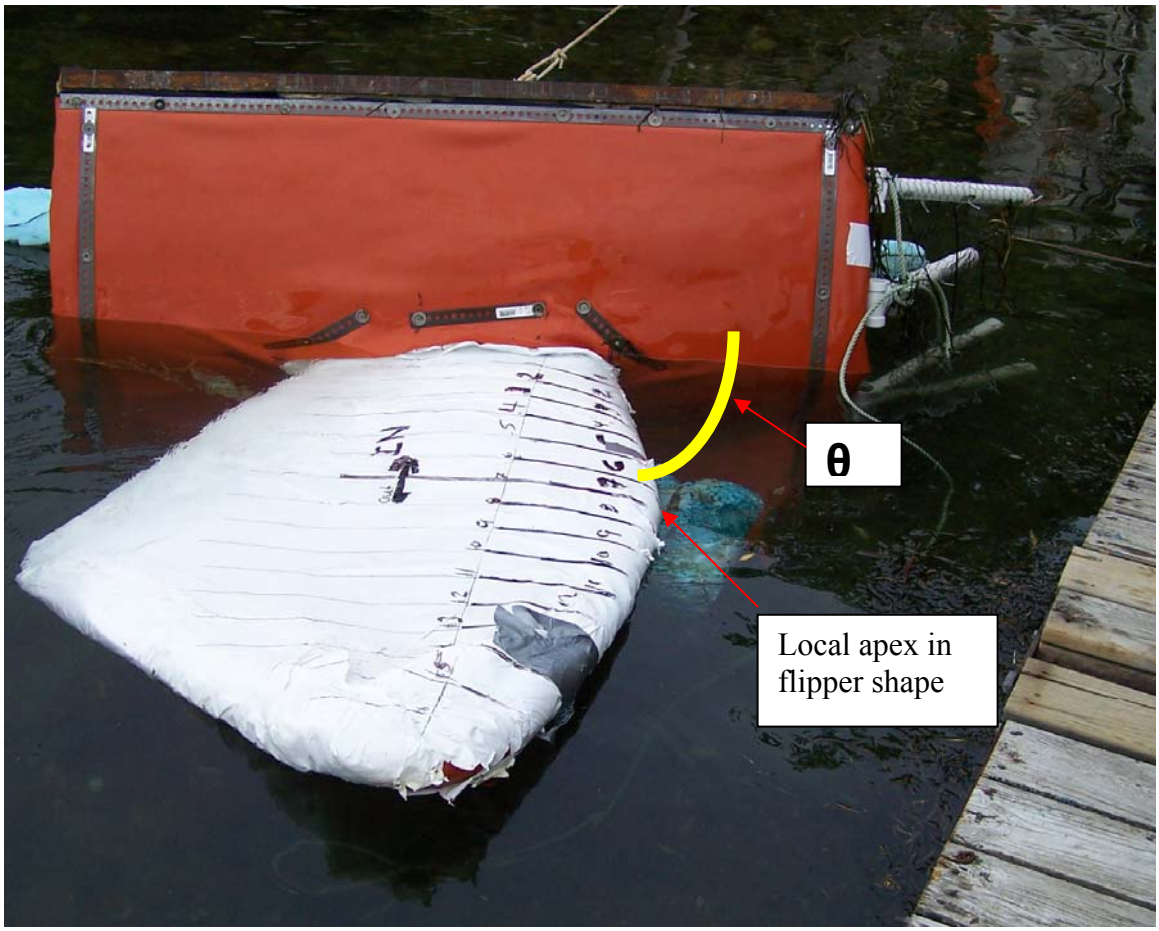

Figure 5. This photograph indicates the angle θ and the local apex in the flipper curve/shape.

Measurements from a series of simulated gear-flipper interactions were taken in 200 trials and over the same number of boat days. The trials were conducted in the Piscataqua River at a site near Frankfurt Island on the Maine side of the river. All the trials were documented with load cell recordings and video of the flipper-line interactions.

The majority of the testing was done with a five-trap trawl. There were two rope types used: Polysteel (PS) and Whale Safe Rope (WSR). The latter was an 1100-pound breaking strength, purple rope developed by Dr. Norm Holy. For some trials, a time-tension line-cutter (TTLC) was attached between the trap end of the vertical line and the traps. The TTLC is a device deployed at the bottom of vertical end lines. It enables the normal loads associated with fishing practices to be applied for a prescribed period of time before the device will sever the end line from the bottom gear. The TTLC has an independent cutting mechanism which allows larger loads for a prescribed amount of time. This time is a critical element of the design, and can be set contingent on the fishing practice. The

TTLC in this experiment was set to cut in approximately five minutes based on room temperature.

Results

There were 201 total trials run with 167 providing data worthy of evaluation (Table 1). Most of the difference in trial numbers was due to missing the vertical line

Table 1. Summary of successful trials by angle θ and position *d*.

d ↓ **/ Angle θ** →	**A**cute	**N**ormal	**O**blique
A: 0-50 cm	29	19	25
B: 50-110 cm	9	15	17
C: 110-176 cm	14	29	10

Load cell output and video camera recordings were acquired for each trial. There were also 'still' images acquired from the boat. All these data were reviewed to create summary histograms and to characterize the flipper-line interactions.

A typical interaction began with the flipper engaging the line, with the line sliding along the edge of the flipper until it reached the float/buoy that would stay with the flipper until all the slack in the line was exhausted. At this point the θ and *d* parameters impacted how the interaction continued.

For angles **A** and **N** the line would snag and stay on the flipper, especially if the contact was within 80cm of the body. Position *A* along the flipper was a snag, while contacts in position B were dependent on where the contact was relative to the local apex along the leading edge of the flipper. The 80cm mark was effectively the local apex.

For angle **O** the line mostly slid off the end of the flipper as the slack expired. The float would be released under the flipper and would surface again downstream, behind the flipper.

Because load varied significantly with the bottom, we analyzed the mean duration of the simulated "entanglement", i.e., the period of time that the rope/buoy system was hung up on the flipper. When the data were analyzed by the distance from the body along the flipper there was a weak trend toward decreasing mean entanglement durations from 38.8 seconds near the body to a mean of 20 seconds at the outermost section of the flipper, but the differences were not statistically significant (Table 2).

However, when we analyzed the mean durations of the simulated entanglements by the angle of the flipper, we found statistically significant differences in entanglement duration. The mean entanglement duration showed a strong decline from 61.6 seconds in the acute (angled forward) position to 20.9 seconds in the normal (right angle) position, to 11.9 seconds in the oblique (angled backwards) position. The mean entanglement durations were significantly different between the acute and normal positions ($p = 0.0147$, two sample t test with unequal variances), and between the normal and oblique positions ($p = 0.117$, two sample t test with unequal variances) (Table 2).

Table 2. Mean duration of entanglement by distance from body to contact on flipper edge and by angle of flipper.

Distance along flipper	0-50 cm	50-110 cm	110-176cm
Mean duration and n	38.8 sec., n=57	25 sec., n= 32	20 sec., n=28
Angle of Flipper	Acute	Normal	Oblique
Mean duration and n	61.6 sec., n=37	20.9 sec., n=38	11.9 sec., n=42

The histogram in Figure 6 provides a graphical summary of the results. The scenarios are defined by θ, *d* and time of the event. Three time frames were selected based on the video review. These time frames were used with all the results: **T1**<15 sec, 15 sec < **T2** < 60 sec and **T3** > 60 sec.

For line interactions occurring with the flipper at an acute angle, positions *A* and *B* are where the interaction lasted for the longest time. Approximately 52% of the interaction resulted in an event lasting 15-60 seconds while 37% lasted longer than 60 seconds at position *A*. A similar result was realized for position *B*. However at position *C*, 67% of the events lasted less than 15 sec and 100% lasted less than 60 seconds.

At the normal angle (N), only 18% of the events lasted longer than 60 seconds at position *A*. Position *B* had 92% of the events less than 60 seconds. The outer position, *C*, had 100% of the events less than 60 seconds, and 80% less than 15 seconds.

When the flipper was at the oblique position (O), the interactions were less than 60 seconds with 80-100% less than 15 seconds. This angle is advantageous for the line to roll off the end of the flipper.

In considering the interaction for all angles combined, at position *C,* 100% of encounters lasted less than 60 seconds regardless of the angle. For position *B,* 12% of the interactions lasted more than 60 seconds, and at position *A*, 17% lasted more than 60 seconds. This percentage based on the entire data set masks the fact that at the acute angle **A** 37% of the interactions are greater than

60 seconds and the percentage of interactions at 60 seconds for position *A* decreases as the flipper angle goes from acute to oblique, as defined earlier.

The type of rope used in these tests had no effect on the results. Both PS and WSR performed the same. The loads encountered were below the breaking strength for each line so that no breaks occurred during the tests. One interesting finding was that even with our five-trap trawl dragged along the bottom at this site for an extended period, there was not ample force to part the WSR. A representative load versus time plot is shown in Figure 7. The ambient drag force is indicated in the beginning of the plot from t=0. The load eventually builds to a plateau and is then released. The up-slope and down-slope of this plot define the time window for the event.

In trials where the WSR was used for the vertical line and was attached to the first trap with a Time Tension Line Cutter (TTLC). The load cell data from an event is shown in Figure 7. At the left side of the plot the ambient drag force of approximately 250 pounds is shown. Over the course of the field trial, this force increases with some variability most likely due to the gear moving along the bottom. A fairly steady load is observed for the majority of the time and then there is an increase followed by a rapid decrease. After this decrease in load the surface float, which was snagged on the flipper, was released over the top of the flipper and a clean, knotless end came to the surface. Upon retrieval of the gear it was observed that the TTLC cut the line cleanly.

The interesting point is that the effective load on the flipper from the gear was 350- 400 pounds. This is well below the breaking load for WSR, but in a region of load magnitude where flesh damage would be anticipated . The TTLC cut the line free after nine minutes at a load below the WSR breaking point. One could conjecture that the gear would have continued to be entangled and cause flesh damage if the TTLC did not cut the line.

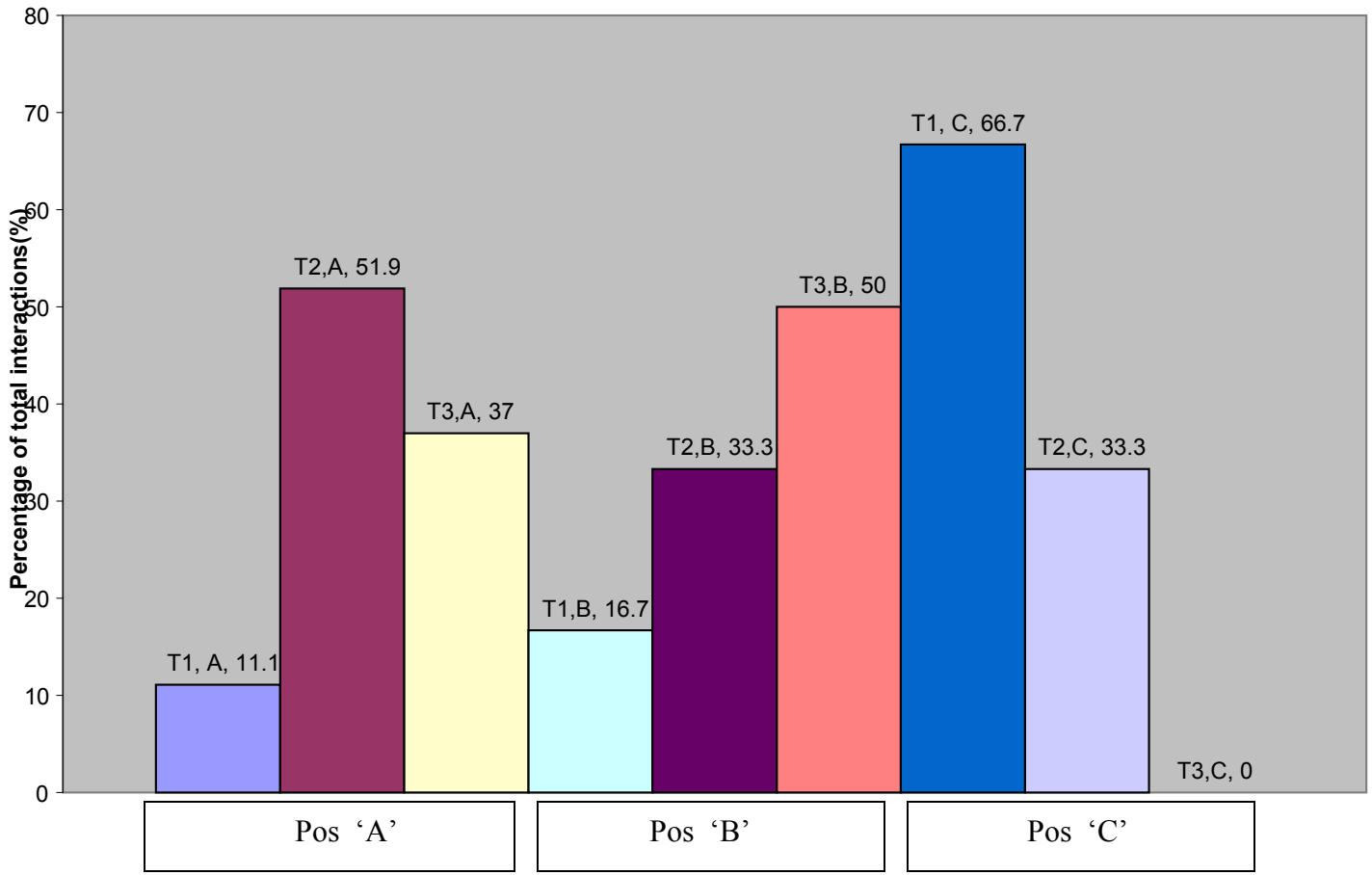

Figure 6. This plot is a summary histogram showing the results of angle **A** for position along the flipper (A, B, C) and time on flipper scenarios where T1 < 15 sec; 15 sec < T2 < 60 sec; T3 >60 sec.

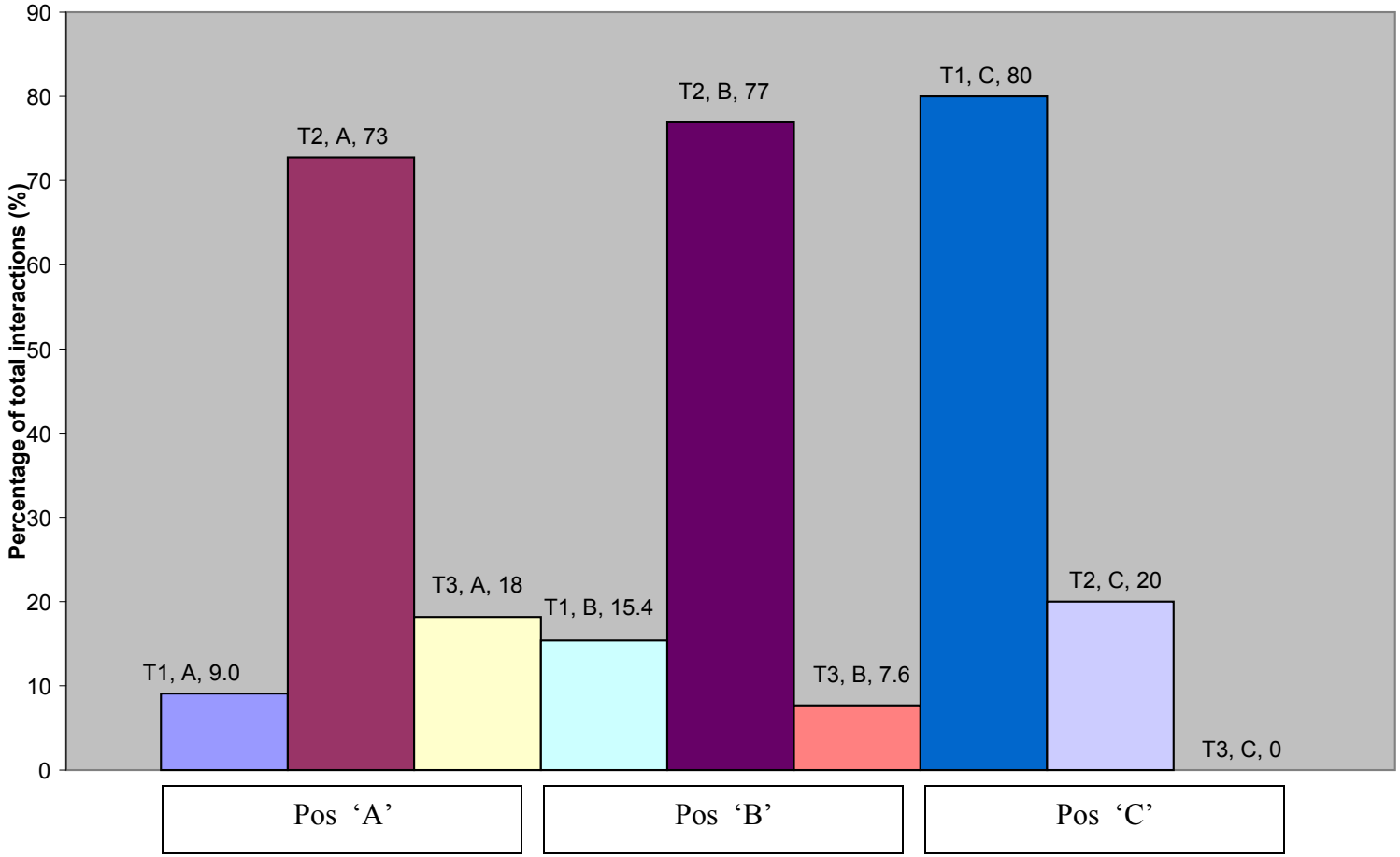

Figure 7. This plot is a summary histogram showing the results of angle **N** for position along the flipper (A, B, C) and time on flipper scenarios where T1 < 15 sec; 15 sec < T2 < 60 sec; T3 >60 sec.

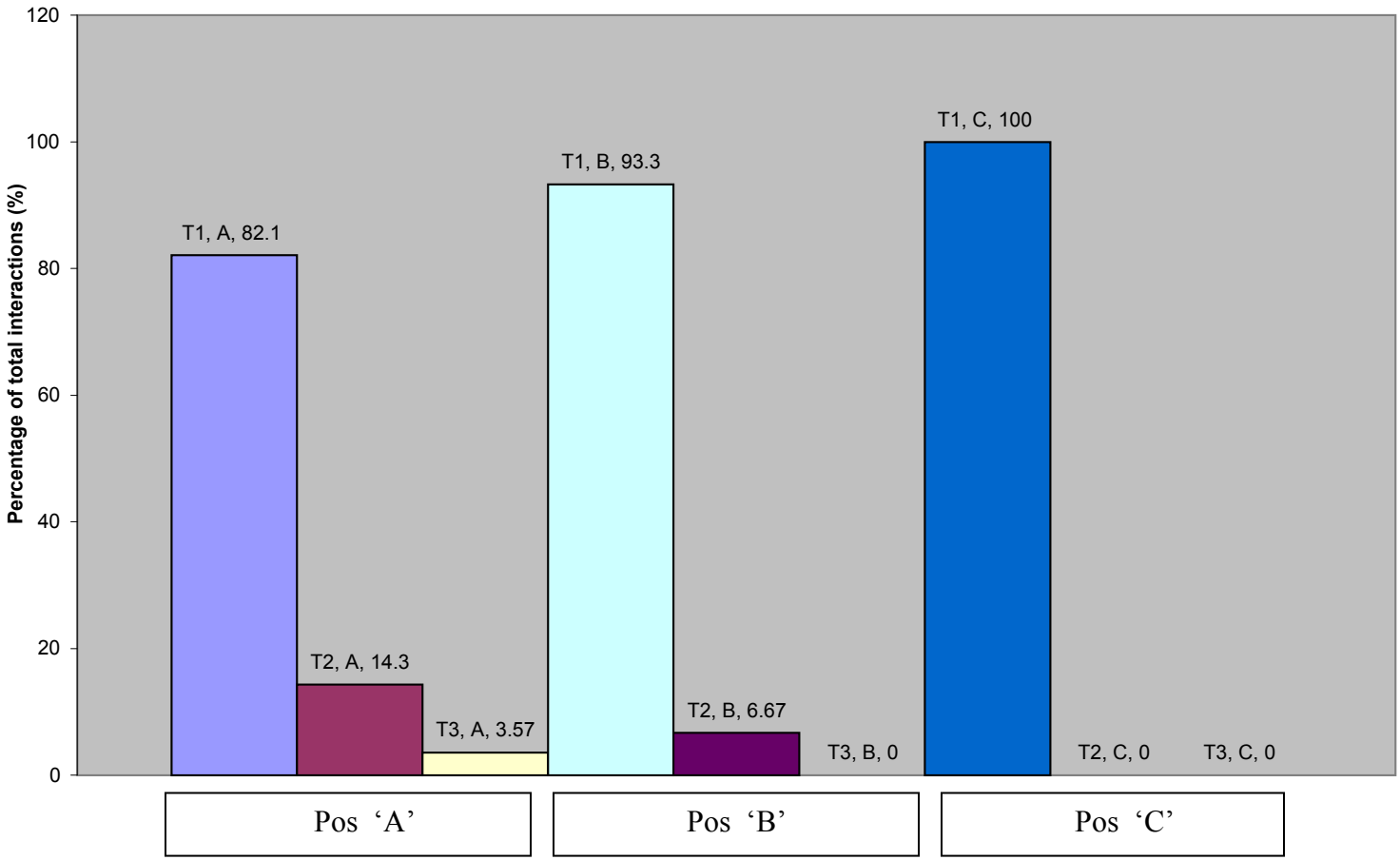

Figure 8. This plot is a summary histogram showing the results of angle **O** for position along the flipper (A, B, C) and time on flipper scenarios where T1 < 15 sec; 15 sec < T2 < 60 sec; T3 >60 sec.

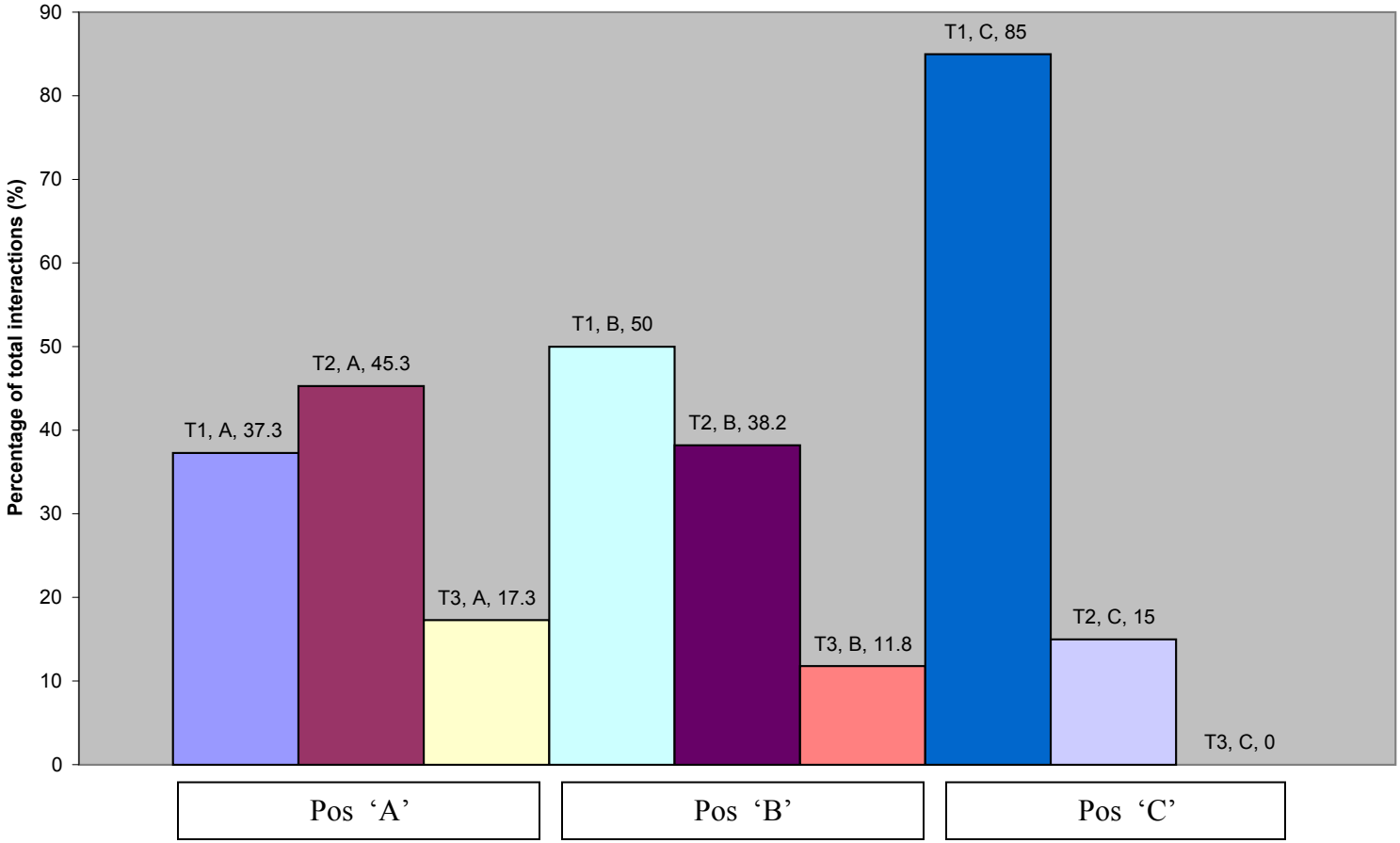

Figure 9. This plot is a summary histogram showing the results of all angles, **A, N**, **O** for all time on flipper and position along the flipper scenarios where T1 < 15 sec; 15 sec < T2 < 60 sec; T3 >60 sec.

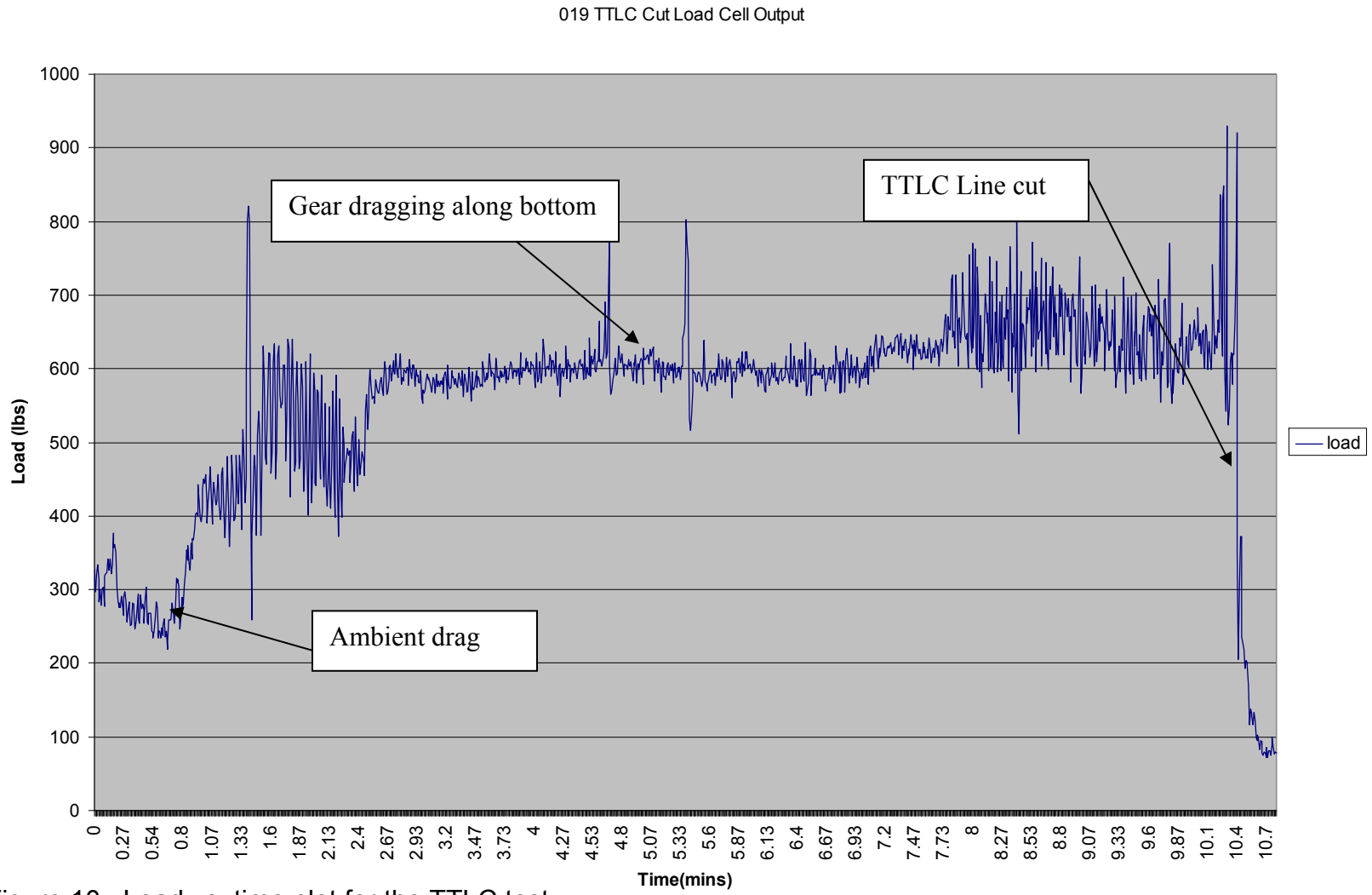

Figure 10. Load vs. time plot for the TTLC test.

Discussion

These trials represent a set of controlled experiments performed to define the interaction of the vertical line with the flipper. Although these tests represent a simplified version of the entanglements by right whale flippers in fishing gear, several important findings did arise.

The statistical analysis of the duration of simulated entanglements suggests that the most important factor in the rapid release of lines from the whale flipper is not the location of the encounter along the leading edge of the flipper, but is instead the angle of the flipper relative to the body. In the cases where the flipper was angled forward, the mean duration of entanglement was almost three times that of the cases in which the flipper was at right angles to the body. Further, the mean duration of entanglements for the normal angled flipper was twice that of a flipper angled backwards. If entanglement risk is dependent upon the length of time a rope/buoy system is hung up on a whale, then this data suggests that it is the animal's behavior (i.e., how it's flippers are held at the point of impact) that is the critical factor in determining whether a whale pulls free of gear.

In none of the experimental entanglements did the load cell readings ever exceed the current NMFS requirements for breaking strength in the weak links at the buoys. In other words, all buoy/rope systems pulled free of the flipper before the weak link would have been activated. This is likely due to the limited number of traps used in the trawl, so that the anchoring weight was reduced below levels that would require a weak link. However, where the simulated whale flipper was near the surface, the rope did slip around its leading edge, pulling the buoy into the flipper. This means that in some circumstances, especially for longer and heavier trap lines, weak links may have the opportunity to work if needed, as they may slide up to the flipper where they could break.

Researchers have speculated that the location and duration of the initial entanglement is correlated with the potential severity of the entanglement. If so, this line of reasoning suggests that if whales could pull free of gear quickly, the frequency of long-term and severe entanglements could be reduced. In these studies, the location on the flipper was not as important in reducing the duration of the simulated entanglements as the angle of the flipper.

Natural flipper angle positions by living whales are used for different purposes. Acute or forward angles are probably used to initiate a turn or a dive, normal (90°) angles are probably used to control pitch in a diving mode, and oblique (backward) angles are used in normal and rapid swimming. Our results, while preliminary, suggest that entanglements may be made worse if the response of a whale to a line encounter is to dive or turn. Diving as a response to the danger posed by a line encounter would be expected. Either response could create flipper angles that increase the duration of the initial entanglement. It is easy to imagine that in a 60 second period (the mean duration of an acute flipper

simulation), a whale in the wild could engage in turning, circling, and rolling. If the flipper is holding the buoy in place because of the acute maneuvering angle, wrapping and further entanglement would seem likely.

Further work using this flipper/gear simulation seems warranted, as it could be used to test alternative ropes, buoy systems, and surface buoys. One immediate line of research that seem promising would be to modify the buoy/line junction to reduce the time that the buoy hangs up on the leading edge of the flipper, by testing modifications particularly in the acute flipper angle mode. The other would be to evaluate the encounter event more rigorously, including modeling of the behavior of the whale at first detection. (If a whale detects the line visually and immediately throw its flippers forward in an avoidance response, does the duration of the initial encounter with the line increase, and is a long term entanglement then more likely to occur?)

In conclusion, these studies have provided some insights into flipper entanglements, and contribute to the development of strategies to reduce entanglements of right whales. In addition, we have demonstrated the utility of a flipper model and simulation platform which may be used for additional testing of gear modifications.

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