Taut Vertical Line and North Atlantic Right Whale Flipper Interaction: Experimental Observations

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This report documents the experimental efforts of the University of New Hampshire, Center for Ocean Engineering and Blue Water Concepts investigating the interaction between a tense vertical line and a physical model of a North Atlantic right whale flipper.

Introduction

The critically endangered North Atlantic right whale, *Eubalaena glacialis*, is threatened by anthropogenic mortality from entanglements and ship strikes (Caswell et al., 1999; Fujiwara and Caswell, 2001; Kraus et al., 2005). Vertical lines used to mark the ends of mobile fishing gear, such as lobster traps, pose one of the leading entanglement threats to large whales. While the initial point of entanglement cannot always be identified, at least one third of right whales observed carrying gear had evidence of flipper involvement (Knowlton pers comm., 2012)

One problem with addressing gear interactions with endangered whales is that it is difficult to conduct meaningful field tests with fishing gear. Entanglements are extremely rare for any given location or fisherman, so testing the entanglement effects of an innovative fishing gear in a realistic manner with sufficient statistical power is not feasible. Thus the Atlantic Large Whale Take Reduction Team (ALWTRT) has attempted to move toward mitigation measures that intuitively reduce risk to large whales, but have not been supported by concrete evidence. 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 are less likely to entangle them or will do less damage to whales if encountered.

In addition, it is hypothesized that a "stiff" line or one with higher tension may reduce the number of entanglements from encounters with vertical lines. In Downeast Maine, vertical lines are taut due to the tension created by strong currents combined with the large surface floats and anchors used to keep gear in place and visible. This configuration also reduces the scope of the vertical line.

It was decided that experiments with a physical model of a flipper, deployed from a moving vessel, and towed into real vertical lines, could help us better understand how North Atlantic right whales interact with normal vertical lines and experimental high tension, "taut" vertical lines.

Methods

Flipper Model

The model flipper was constructed using data acquired from three different whales that included flipper outlines and bone measurements. From this data, a computer generated model flipper was developed. Sections of the flipper were extracted from this computer model and formed the basis of the flipper construction. The physical model of the flipper was covered with ½" neoprene rubber which was subsequently overlaid with 1/8" thick vinyl rubber sheeting. This was the same fabrication used the original flipper testing in 2007 (Baldwin et al, 2007). Other choices for material were investigated for the 2007 fabrication but were rejected due to high expense. We decided the neoprene/vinyl rubber combination was an adequate match for and emulated the outer surface of the NARW flipper. This was considered a cost-effective construction and duplicated in the new flipper so the response of the flipper to the slack vs. taut vertical line could be more readily compared.

This flipper and frame were successfully used in full-scale interaction experiments with vertical lines, which was documented in (Baldwin et al., 2007) and the presented at the North Atlantic Right Whale Consortium meeting in November 2007.

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

The experimental protocol called for adjusting the flipper angle relative to the 'whale side'. The forward/aft position and where the interaction happened along the flipper leading edge were key criteria. The three zones along the leading edge are indicated on Figure 2 as 'A', 'B', and 'C'. The angles (θ) are defined as**:** A: Acute (forward); N: Normal; O: Oblique (rear) relative to the whale body panel of the physical model.

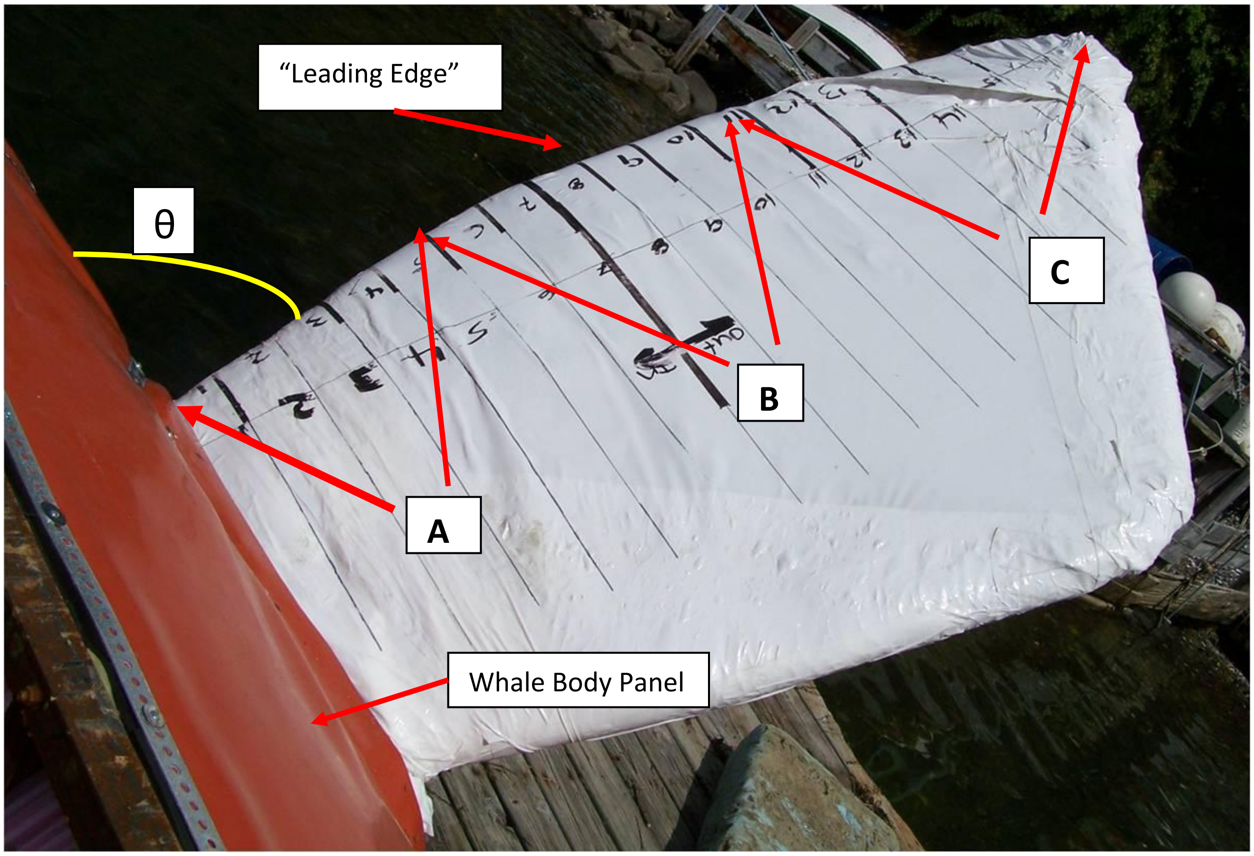

Figure 2. Position parameters for defining the zones along the flipper leading edge and the angle of the flipper relative to the whale body panel. 'A' : 0-50 cm; 'B' : 50-110 cm; 'c': 110 cm to the tip. (Adapted from Baldwin et al 2007)

Previous Trials

The results of previous trials (Baldwin et al., 2007) are summarized here:

- Line/flipper interactions were as anticipated: for angles 'A' & 'N' the line would snag and stay on the flipper, especially if it hit inside 80 cm
- For hits beyond 80 cm the buoy would remain above the water until all the slack expired, then the buoy would release under the flipper
- For angle 'O' the line mostly slid off the end of the flipper as the slack expired and the line gained tension
- The process was independent of line type used (i.e. sinking, polypropylene, nylon)

Taut Line Experiments

Salty Boat Company used the original flipper as a mold to fabricate a new physical model flipper for the taut line testing. The new flipper was made from fiberglass and was free flooding, rendering it lighter than the previous concrete ballasted model. The flipper's leading edge was covered with ½" neoprene which was subsequently covered with 1/8” vinyl-rubber. The flipper was marked with zones along the leading edge moving out from the body element to the tip of the flipper. The section from the body out to 60cm was ‘A’, from 60 – 120 cm was ‘B’ and from 120 out to the tip was ‘C’. These zones were marked in ten cm intervals.

The flipper was deployed approximately 12’ below the surface using a frame, attached to the *Jesse B* (Figure 3). This picture shows the frame without the flipper during a trial to observe the vessel behavior with the frame attached.

Figure 3. The flipper deployment frame mounted on the *Jesse B*. The flipper is lowered to a position under the vessel when the ‘arms’ are in a vertical position

A new mooring system was fabricated to create the taut vertical line using a large mooring block in the harbor in Eliot, Maine. The existing mooring block was fitted with a pulley and a swivel. The vertical line being tested was at least twice the water depth at mean high water (MHW) in length so the line could be changed by releasing the tension and replacing the experimental section with a different line. A 5/8” line was attached to a 28” diameter float, guided down through the pulley at the block, and attached to a longer sinking line which ran along the bottom to the shore. The float used to create the buoyancy was typical of those used by lobstermen. It was deployed at the test site at low tide and the line attached to it was pre-loaded at this point in time. The shoreline was surveyed earlier for a suitable ‘fixed point’ for securing the line when it was under tension. The line was terminated with an in-line load cell, attached to the fixed point, for measuring the tension in the line. A schematic of the mooring system is shown in Figure 4.

Line tension measurements were first recorded at low water (LW). The float was pulled under water from the shore and secured to the load cell at the fixed point on the shore. As the tide rose, the load was monitored until the float was completely submerged.

Experiments in the field began in August 2011. The flipper deployment frame was assembled on the *Jesse B*. A few trial runs were made without the flipper to get a feel for how the frame would affect boat steering. The flipper was attached and more trial runs were made until the crew was confident with steerage of the boat.

Two cameras were set up to observe the flipper-line interactions and a third was used to monitor the boat course. One camera was placed to look out along the flipper leading edge. A second was mounted to the flipper frame to look down along the flipper. A four channel DVR was used to record the video. The DVR was able to record and save the video on the internal hard drive.

After all the preliminary checks were completed, testing was delayed due to weather. Everything was removed from the water and boats were moved to safe locations or pulled from the water. The next testing date was October 1, 2011 after the weather improved and everything was reassembled. It should be noted that after large weather events which produce a large run-off the estuary is fairly turbid for up to two weeks.

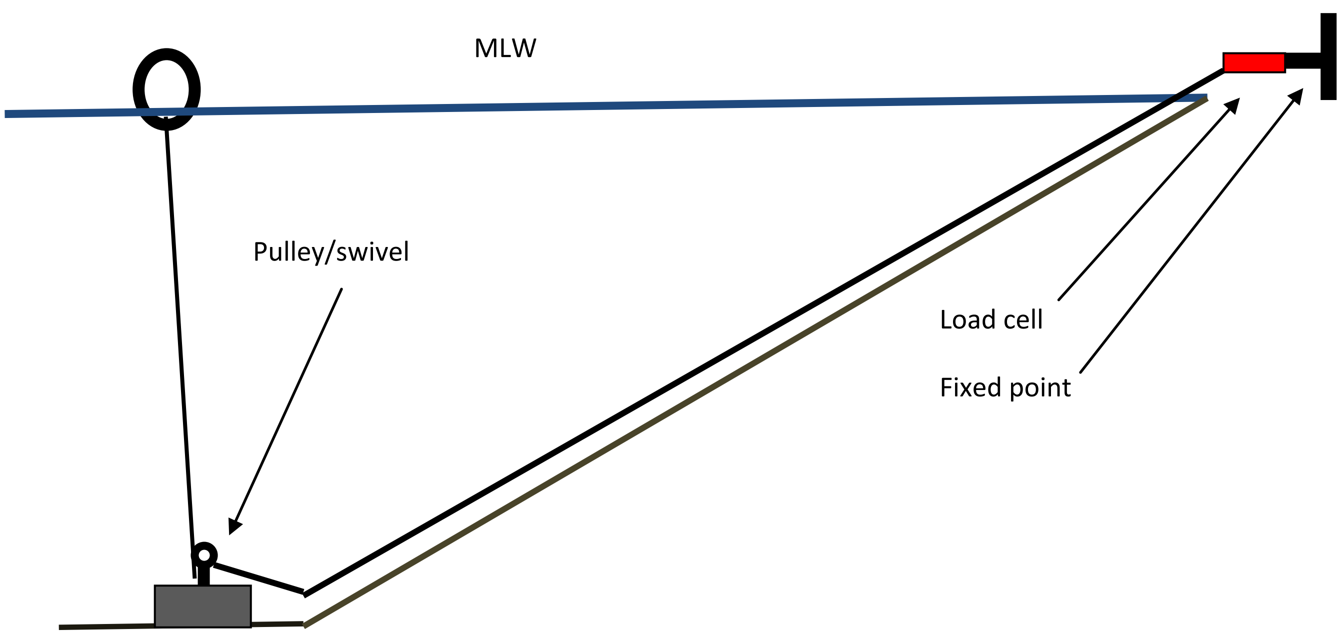

Figure 4. Schematic of mooring/taut line system indicating load cell placement at the fixed point.

Results

The tension of the line, with a fully submerged 28” in diameter float, was 415 lbs. This value is based on the displacement of a sphere 28” in diameter using water density of 62.4 lb/ ft^3. This value did not account for the weight of the float nor was the actual density of the water used, but the value was considered an acceptable estimate. The float was inflated in air at approximately 75° F and then submerged in water which was cooler (approximately 55° F) hence the sphere could easily have contracted. For these reasons, line tension measurements that were within 20% of this estimated value were deemed acceptable.

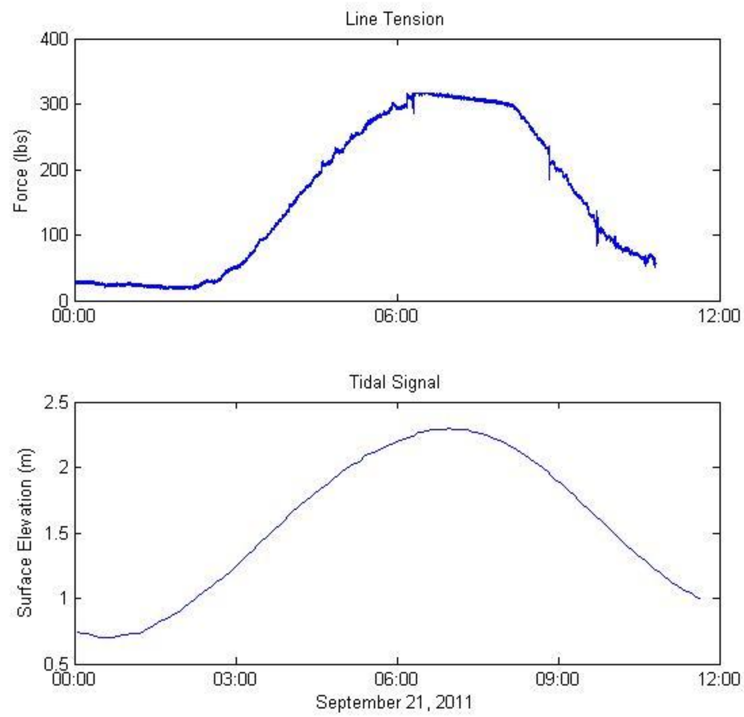

Figure 5. Measured line tension is shown in the top plot and the corresponding tide signal is shown in the bottom plot. The maximum tension was 325 lbs.

The line tension was continuously monitored over a 12 hour period. At high tide, the float was completely submerged, providing maximum line tension of 325 lbs (Figure 5).

Trials with the flipper began on October 1, 2010, in the afternoon during high tide and maximum line tension. The flipper was in the neutral, ‘N’, position relative to the body side panel. The boat was driven at 2 knots into the vertical line. Thirty three interactions between the flipper and the line were recorded. The first group of 11 runs was mixed, hitting all areas of the flipper leading edge: A, B, and C. These trials were considered ‘learning curve’ observations.

Observations from the next 11 trials were recorded. Six events of that group were glancing interactions, in zone C, the outer edge of the flipper. These events occurred quickly, in less than two seconds. The remaining five interactions were at zones A and B areas. During these interactions, the float moved vertically down in the water column with a slight angle towards the back edge of the flipper (Figure 6).

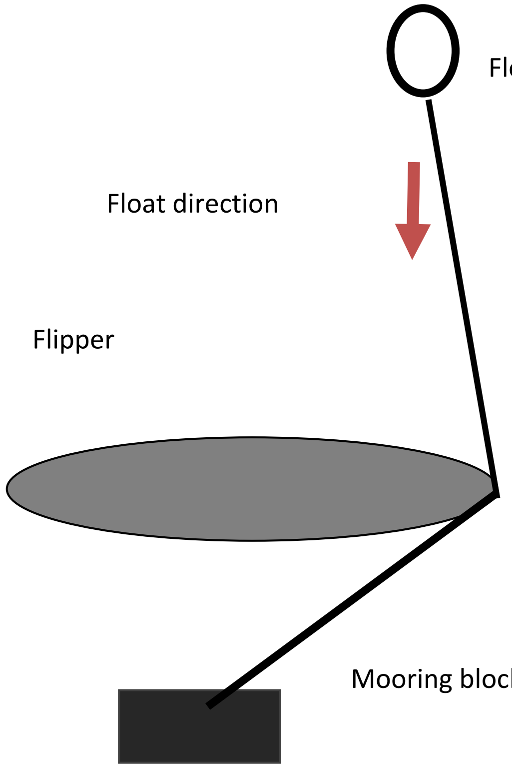

Figure 6. Schematic of the components of the line-flipper interaction. Red arrows indicate the motion of the flipper and the float.

The basic contact geometry resulting from zone A and B contacts showed a downward motion of the float as the dominant movement. After this group of events, it was observed that the material at the leading edge of the flipper was coming apart. Pieces of the vinyl rubber were moving about in the flow and pieces of the neoprene came to the surface. The resulting leading edge is shown in Figure 7.

The next eleven trails occurred in zone A and B, except one glancing event in zone C. During the A and B zone interactions, the float was observed to move downward as shown in Figure 6 in all cases. Some of the contacts that occurred in zone A caused the *Jesse B* to list starboard, leading the event to be terminated. Contact between the line and flipper was ended by slowing the Jessie B, usually when the float reached the flipper edge. A summary of the events is displayed in Table 1.

The glancing events were 2 to 4 seconds in length and the line simply slid off the end of the flipper after contact. The events where the line snagged and the float submerged down to the flipper had an estimated 7 seconds maximum limit, based on the geometry of the mooring line and the speed (2kts) of the *Jesse B*.

Figure 7. A series of after the fact pictures showing the status of the leading edge of the flipper. The top two pictures show a scalloped edge which is most likely resulting from a ‘sawing action’ of the line as the float descended.

Table 1. The log book summary of the contact events is presented with an event number for correlating with the video and area of event, 'A', 'B', 'C'. The * indicates that the contact area is not clear. Some events were defined as 'A-B' in the notes

Event #	Event Area		
	'A'	'B'	'C'
1*			
2			X
3			X
4		X	
5		X	
6		X	
7			X
8			X
9*			
10			X
11	X		
12			X
13			X
14			X
15			X
16		X	
17			X
18			X
19	X		
20		X	
21	X		
22	X	X	
23*			
24	X		
25	X		
26	X		
27		X	
28			X
29	X		
30	X		
31	X		
32		X	
Total	**10**	**8**	**11**

Discussion

Observations from the video cameras and the final condition of the flipper's leading edge provide some insights into the nature of collisions between high-tension vertical lines and North Atlantic right whale flippers. When the line engaged the flipper in zone 'A' or 'B' along the leading edge a downward movement of the surface float was observed and an apparent 'sawing action' occurred which resulted in significant damage to the leading edge of the flipper (Figure 7). The damage to the flipper's leading edge was clearly visible after 22 events, and 11 of these 22 events were just glancing events. It did not even take prolonged contact between the line and the flipper to cause this shredding. During each collision event, the *Jesse B* would list precariously starboard and each interaction event was therefore terminated only after 2-7 seconds had elapsed.

As shown in Figure 6, the line had little horizontal displacement before the vertical movement dominated and the line began to cut into the flipper. Vertical movement of a fishing rope across the edge of a baleen flipper can lead to the removal of epidermal tissue even under much lower tension than that used in this trial (Winn et al., 2008). In previous flipper-line collisions using a similar flipper model and under similar environmental conditions, there was more line in the water and a smaller toggle buoy at the surface such that the vertical line was far less taut (Baldwin, 2007). The additional scope provided more opportunity for the line to move along the flipper inward or outward relative to the body as the flipper moved forward under the propulsion of the *Jesse B.* These events were of much longer duration, ranging from 11.6 to 61.6 seconds.

The large surface float required to generate the high, ambient tension on the vertical line was not easily shed from the flipper. The float and the subsequent line tension essentially caused more snagging of the float as there was little room, temporally or spatially, for movement. If the experiments had been carried out in deeper water with longer, but still taut, lines, there would be more time for the float to move downward and possibly be shed from the flipper.

Originally, one goal of this project was to test two different diameter lines. The 5/8" diameter line was larger than lines tested in the 2007 experiments, and was the largest line planned for this series of experiments. During the trials, the 5/8" diameter line was observed sawing into the flipper leading edge. Due to this damage, it was decided that smaller line under similar tension would do more harm to the flipper, so no other diameters were tested. Support for this decision comes from abrasion tests using different fishing ropes and whale flipper tissue retrieved from entangled necropsied whales, in which ropes with lower diameters were more likely to cut into the epidermis (Woodward et al., 2006; Winn et al., 2008).

There are several obvious limitations in extrapolating the results of these trials to what actually occurs when right whales collide flipper first with vertical fishing ropes. Although the model flipper was constructed to be anatomically accurate and capable of slight sweeping movements both forward and aft, its covering, body attachment, and articulation were clearly different than what occur on a live animal. Furthermore, the rig is not appropriate for evaluating a more dynamic and prolonged interaction, such as were a whale to roll its body following contact with the gear, as was observed when a humpback whale came into contact with a gill net rope (Weinrich 1999). The results do suggest however that in evaluating the potential of stiff rope for reducing the incidence of large whale entanglements, consideration should be given to a possible increase in the probability that they would cause lacerations, at least for entanglement events in which the first point of contact is the whale flipper. This may especially be true if the intense force exerted against the flipper's leading edge as a swimming whale moves into it may embed the line before it has a chance to slide off the outer tip. Although the results of this experiment should not condemn the potential bycatch reduction benefits of using a stiffer vertical line in trap and gillnet fishing, they do provide important insights that in combination with further research can help in its evaluation.

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