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The Time Tension Line Cutter Evaluation: Fishermen Pilot Study and Controlled Experiments

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INTRODUCTION

This project addressed issues related to the S-K program priority on Right Whale Gear Entanglement Mitigation Research. Specifically the project goal was to define the operational parameters of the Time Tension Line Cutter (TTLC) for use in the vertical lines of fixed fishing gear. Any mitigation strategy designed to minimize entanglement with NARW must be benign to the whale and easily integrated into the fishing operation. Clarifying these definitions was the essence of this project.

The TTLC needs to be placed in context of other concepts used as mitigation strategies for reduction of vertical line entanglement. When one considers the other strategies in the basic framework of safety to the whale and easy integration into the fishing practice the TTLC shows promise. 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 pre-set amount of time then the device severs the end line from the bottom gear. A struggling animal would then be freed and avoiding tissue damage associated with long term tightly wrapped lines, or drowning. The TTLC provides a solution to the shortcomings of the previous mitigation strategies. The TTLC allows the use of higher strength lines which the fishing community presently uses. This allows loads greater than 1100lb to be generated during hauling. The TTLC achieves this by having 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 basic principle of operation moves hydraulic oil through a load sensing, metered orifice which pushes a piston against a spring (US Patent Number 6,928.765 B2). The displacement of the piston begins the process of moving a ‘cutting blade’ through the line. The time to cut is defined by the orifice size and the hydraulic oil viscosity. The load required to begin this movement is lower than the working load of the line, but the larger working loads do not cut the line instantaneously. This enables the fisherman to use the maximum line capacity until the preset time is exceeded.

The project had two main components. One was a pilot study with the fishing community and the second is more experimental. The fishing community members

participating in this study were required to complete data logs. These logs had a set of parameters to record. The periodic inspection and testing of the TTLC will be part of this record.

The second component of the project involved experimentation to study end line loads with a TTLC installed. Some gear in this case would be dragged on the bottom, and some gear would be dragged through the water. The loads were measured during these experiments. The load vs. time records display how much load and time was required to cut the lines. Gear which becomes entangled on a whale will either be dragged across the bottom in one extreme or dragged through the water column, or some combination of the two scenarios. The objective of this testing was to evaluate the ability of the TTLC to cut the line of entangled gear. This work was done using the *Jesse B* which was fitted out to tow the gear and provided a fixed station for measuring loads. Effectively the *Jesse B* became the whale with the gear attached. The critical elements of this testing program were to measure the loads vs. time, and to know where the gear was relative to the bottom.

The two components of this proposal will be accomplished in different arenas. The pilot study will address the fishing industry use of the TTLC, and the controlled experiments will enhance the understanding of how the TTLC will be beneficial to the whale. The controlled experiments will yield quantitative data regarding gear being dragged along the bottom, and gear being dragged through the water column. The latter case will provide data regarding potential harm to the whale and how the release of the gear will be positive.

METHODOLOGY

There were two components to the work in this project. Each had its own methodology which was appropriate for the task. The towing component was a structured set of experiments to observe with the proper sensors the loads in the vertical line and positions of individual traps in the water column when the gear was in a steady state situation. The pilot study was a less structured task as its outcome was at the will of the volunteers, the sea, and the fishing economy.

Tow Testing

In the summer of 2008, data were collected to characterize the dynamics of a trawl of lobster gear in tow. This was done to simulate the behavior of the trawl after becoming entangled with a traveling whale. The data that were collected consisted of pressure readings from five Star-Oddi self-recording pressure sensors deployed in selected traps and end line loads collected using an Omega LC 203-2.5K, 2500lb capacity load cell. Variables that were tested were the water depth, number of traps in the trawl, and relative scope of the end lines (tow lines).

Gear Used

The traps used in these tests were four foot, four brick traps, which are typical of the near shore lobster fishery. They were attached to a ground line with a one fathom gangion (Figure 1), with the spacing between traps of seven fathoms (Figure 1). The heads of the traps were removed and the openings wired shut to ensure that the traps were completely un-fishable. This ground line was then attached to a short (~1 fathom) section of line to which the bottom of the TTLC would attach. From this short piece, a longer safety line was spliced to remain attached to the traps once the TTLC would cut the line. The end line was then attached to the top (cutting end) of the TTLC, and the longer safety line was spliced further up the end line. A loop was tied in the top side end of the end line to facilitate easy fastening to the load cell via a shackle.

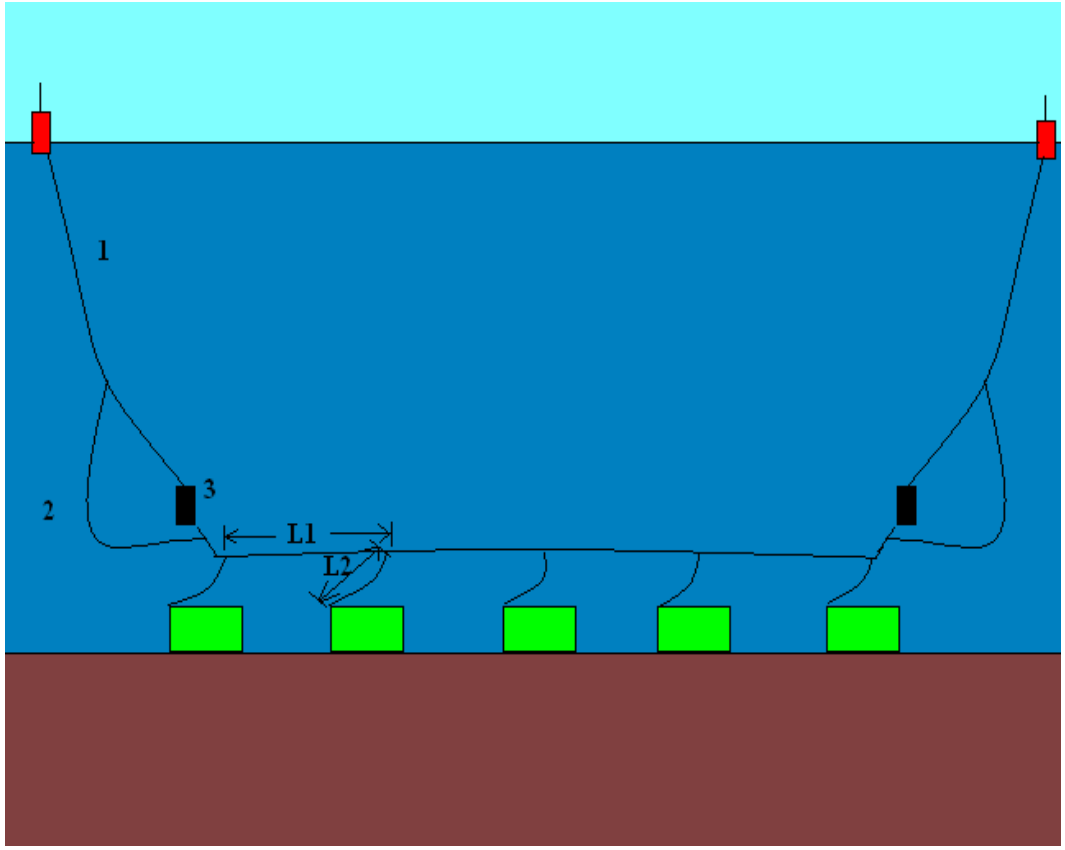


Figure 1. Diagram of towed gear configuration. 1. End line from buoy at surface to TTLC at the bottom. 2. Safety "jumper" keeps end line connected to ground line after the TTLC is cut (under normal fishing circumstances, this would not be attached to the end line above the TTLC). 3. The TTLC. L1 is the distance between gangions, ~7Fa, L2 is the gangion length ~1Fa.

Star-Oddi Pressure Sensors

The pressure sensors used in this testing procedure were Star-Oddi DST Milli self recording pressure/temperature loggers (Figure 2). The pressure resolution with the logger is 0.03% of the depth range or approximately 0.9 cm in 30 meters of water. These were mounted in traps on the gear trawl to record the depth of the trap and hence the elevation of any given trap in the trawl, while in tow. These loggers were programmed, and the data subsequently downloaded via a communication box which was connected to a PC running the Star-Oddi software SeaStar (Figure 2). The loggers could be set to record both temperature and pressure, and could also convert pressures into corresponding depths.

Sampling rate, and start time could also be preset by the user via the communication box.

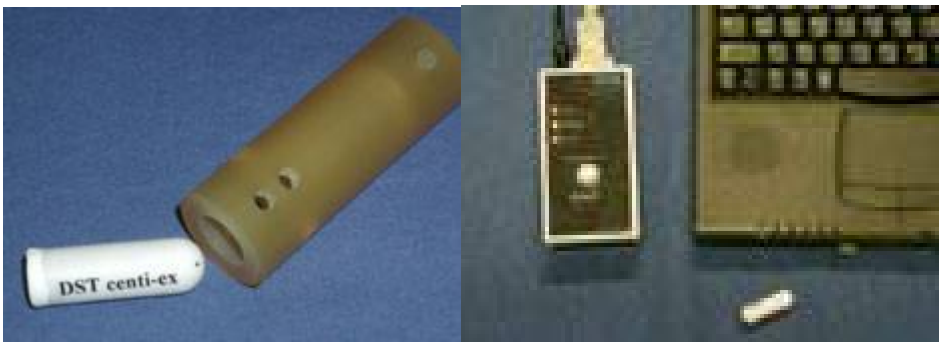


Figure 2. Star-Oddi and Communication Box. Images of a Star-Oddi mini logger with the protective housing, as well as the communication box that allows the loggers to be controlled (turned on, off, adjusted etc.) through a laptop while in the field. (Photo Courtesy of Star-Oddi)

The programmed loggers were placed into perforated rubber sleeves before being tied into the wire mesh of traps. The purpose of the sleeve was to protect the fragile components of the loggers as well as providing a secure method of attaching the loggers to a trap. After a series of tests were completed, the loggers were removed from their respective traps and placed back into the communication box to download the data and be turned off. The data were in the form of a .txt file that could easily be used for processing in either Matlab or Excel.

Load Cell

Monitoring the load in the end line provided a load vs. time record which was used to evaluate the performance of the TTLCs, and to provide a relationship between the Star-Oddi trap-elevation data vs. tension in the endline. The load cell that was used was an Omegadyne Omega LC 203-2.5K, 2500lb capacity load cell. The output voltage from the load cell was amplified using an Omega DMD-465 signal amplifier whose gain was adjusted to scale the sensitivity of the output voltage of 0-10V to 0-2500lbs. This 0-10V output voltage was then fed through a National Instruments NI USB-6009 analog-digital converter, which was fed into a computer via USB cable (Figure 3). This signal

was then processed by a LabView Program that converted the output voltage to load in pounds using the calibrated sensitivity (Baldwin and Landino, 2007).

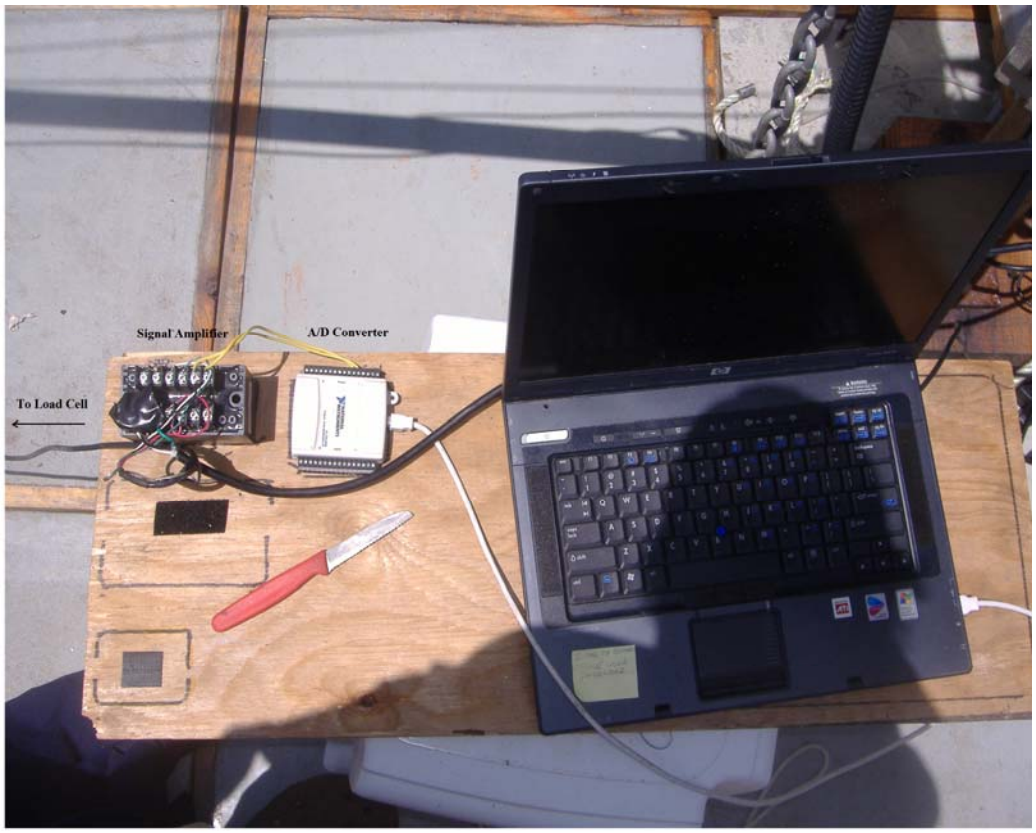


Figure 3. Setup to record load cell on the *Jesse B.* The wire on the left hand side of the picture is coming from the load cell. It then enters the signal amplifier (black box) and then is sent through an A-D board (white box) and then to the laptop running the LabView Software.

Testing Setup

The testing platform for this series of experiments was the *Jesse B* owned and operated by Blue Water Concepts of Eliot ME. The *Jesse B* was outfitted with a gin pole which could be moved up and out of the way while the boat was underway, and down into the "tow" position. The load cell was fixed to the end of the pole during a tow using a shackle. Next, the end line was secured to the load cell with a shackle. Lowering the gin pole down from the upright position placed the point of pulling as close to the water as possible to mimic the angle at which an entangled whale would be pulling the gear while maintaining maneuverability of the vessel (Figure 4).

The Star-Oddi loggers were placed in sequence depending on the number of traps in the test trawl. There were five loggers on loan from John Kenney. In a five-trap trawl, a logger was placed in every trap. In a 10 trap trawl loggers were placed in traps 1, 3, 5, 8, and 10. In the 20-trap trawl, loggers were placed in the same configuration as a 10-trap trawl, which meant that either the first or last 10 traps in the trawl had loggers in them, depending on which end line was being pulled.

In the 20-trap trawl towing the scope (length of line to depth of water ratio) of the end line was varied on each line, from short to long, rather than just having one end line being short and one being long, as was done in all of five and ten-trap trawls. This enabled a both scopes to be tested with the Starr-Odi pressure recorders in the first ten traps or the last ten traps. The definition of "short" scope was taken as 1.33 times the depth of the water, and "long" scope was defined as 2.4 times the depth of the water. These values were held constant throughout the whole experiment, to ensure that the values of scope were consistent when the test site (ie. water depth) was changed.

Figure 4. Gin pole on *Jesse B* in the testing position. The load cell is at the connection point between the pole and the end line being towed.

Pilot Study

Starting in the summer of 2008, a pilot study was initiated to test the robustness and "fishability" of the TTLC in near shore lobster fishery in the GOM. Fifty TTLCs were acquired from Blue Water Concepts of Eliot ME in mid summer and were available for threshold testing by late summer. Each unit was threshold tested before being given to the fisherman for at-sea testing. This baseline testing was preformed to verify the operation of the TTLC, find the initial time to cut (TTC) of each unit, and to insure that the TTC was adequate to fish safely.

Initial TTC Evaluation: Threshold testing

Threshold testing was done in the engineering tank at the Chase Ocean Engineering Laboratory at UNH. This was done by using the same load recording apparatus used for the tow testing to measure the load and TTC. A section of steamer chain (450lb submerged weight) was used as a dead weight to apply the amount of force required to initiate the cutting sequence of the TTLC. The TTLC was attached to the chain via short piece of line at the bottom of the unit, and then attached at the top (cutting end) via another section of line coming from the load cell. The load cell was then attached to the crane, which would allow the chain to be picked up off of the floor, and placed in the tank, thereby applying the load (weight) of the chain on the mechanism of the TTLC, initiating the cutting process. A safety line was attached from the chain to the crane to prevent the chain from sinking to the bottom of the tank after the line connecting the TTLC to the crane was cut. A diagram of this setup is shown in Figure 5.

As the TTLC is engaged under load a gap opens between the two main body parts. This gap is related to the engagement of the cutting blade with the line and hence an indicator of the TTC. To facilitate the observations by the lobster fishers, the aluminum sleeve containing the moving parts of the TTLC was marked with color coded increments corresponding to the advancement of the blade in the cutting process (Figure 6). These increments were painted to correspond with how close the TTLC was to cutting the line with green being the least time elapsed, then yellow, then orange being the closest to a cut. This

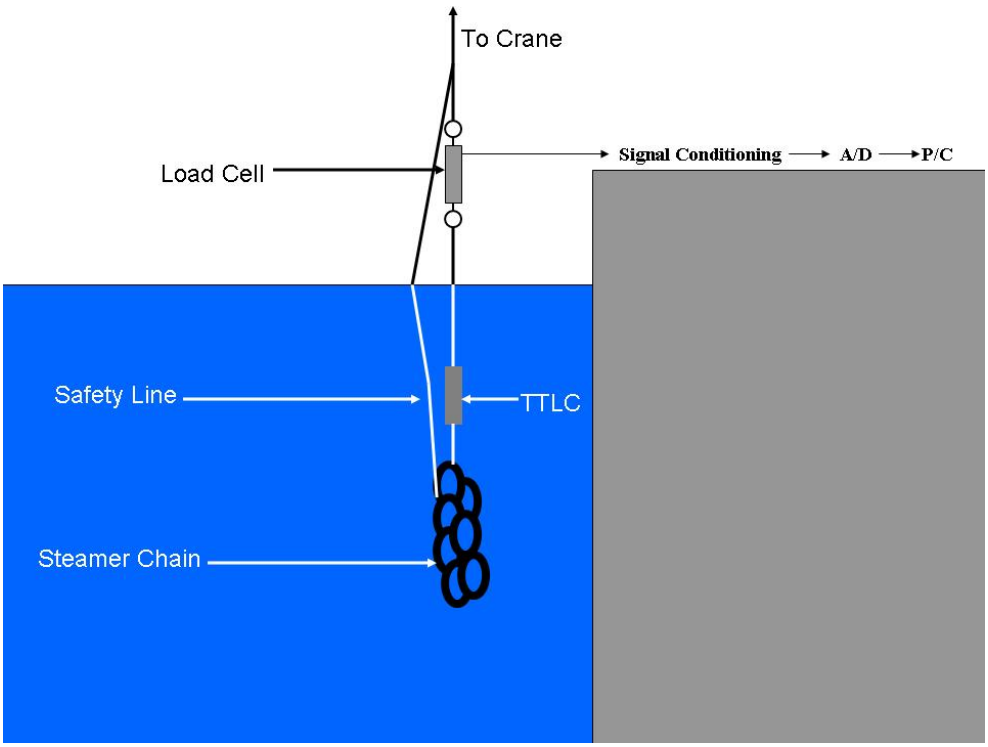


Figure 5. Diagram of calibration setup

was done to allow the fisherman have a warning of when the TTLC was going to cut, as well as allowing for an easy way to assess the gap on the TTLC when it was being hauled.

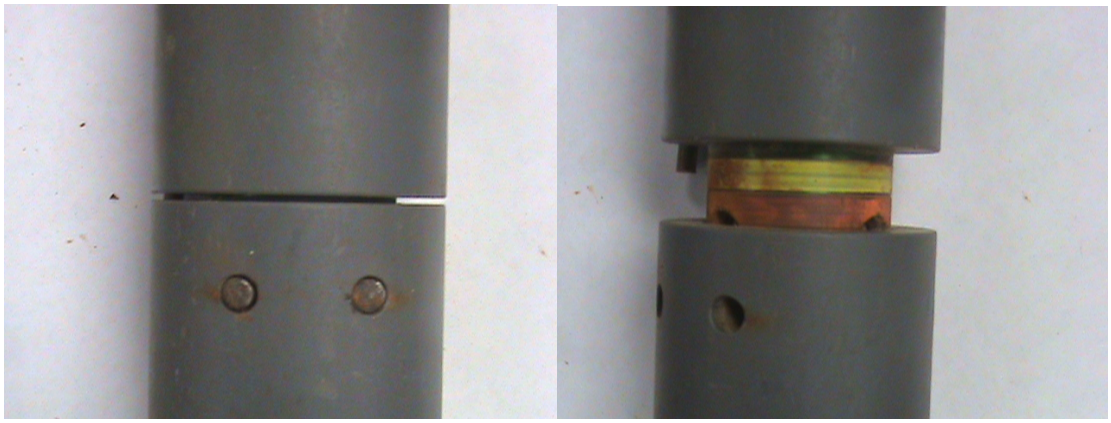


Figure 6. TTLC before and after cut. The picture of the gap (top) in TTLC with no load applied, notice the lack of a gap between the upper and lower plastic housing pieces. The picture of the gap (bottom) in TTLC after it reaches TTC, note green, yellow, and orange time indicator bands.

Identifying fisherman

It was initially proposed to identify ten fishers from MA, NH, and ME to each fish five TTLCs, while periodically sending the units back to UNH for re-calibration. The selection process involved communications with Dan McKeirnan the Maine Lobster Association. Dan McKeirnan provided names of people in the lobster fishery from Gloucester and the MLA provided the name of one person. The people from Gloucester were contacted and there were no candidates interested. Hence, due to these factors regarding availability of candidates for this study, it was decided that having five boats fish ten TTLCs was more feasible. The final volunteers are listed later in this report.

Suggested Rigging

When the units were being distributed, each candidate fisherman was provided with a description of how the devices work, and suggested rigging techniques, although the rigging methods undertaken are ultimately the decision of the fisherman. Since the TTLC is rigid compared to the rest of the end line, the TTLC must bypass the hauling mechanism rather than simply being cycled through. Figures 7 and 8 show the suggested rigging of the TTLC, and how this rigging would be used to haul gear. Figure 7 shows the TTLC approaching the block on the hauling davit with the jumper line trailing the TTLC which would be used to bypass the TTLC when hauled. At this time, the jumper line and end line would be swapped in the hauler, removing the tension from the TTLC and allowing it to bypass the block and hauler much like a trap on a trawl (Figure 8).

Figure 7. Rigging method. This image shows the suggested rigging method as fished on the F/V *Rough Times* of Portsmouth NH. (1) The hydraulic plate-style hauler. (2) End line above and below TTLC. (3) The block hanging off of the davit on the starboard side of the vessel. (4) The TTLC. (5) The "jumper" spliced into the bottom of the end line, used to bypass the TTLC around the hauling apparatus.

Figure 8. Jumping the block. This image shows the hauling procedure for the TTLC. The end line (2) is being swapped with the jumper line (5) removing tension in the TTLC by switching the load from the end line to the jumper, the TTLC (4) is then bypassed around both the block (3) and the hauler (1).

DATA COLLECTION / REDUCTION

The data collection and reduction for the two components of this study are presented here. The tow test data were collected electronically, using the pressure sensors and the load cell, while the pilot study data consisted of the log sheets filled out by the fisherman in the study, and the subsequent TTC evaluation.

Tow Test

The data were collected during the summer of 2008 from late June to early August aboard the *Jesse B*. The base station for the majority of the tests was the Blue Water Concepts Pier in Eliot ME, while two other test days were staged out of the NH State Pier in Hampton NH. Three different test sites (Figure 9) were selected, all with different water depths, for their accessibility, and the lack of gear present to avoid entangling and or molesting resident gear.

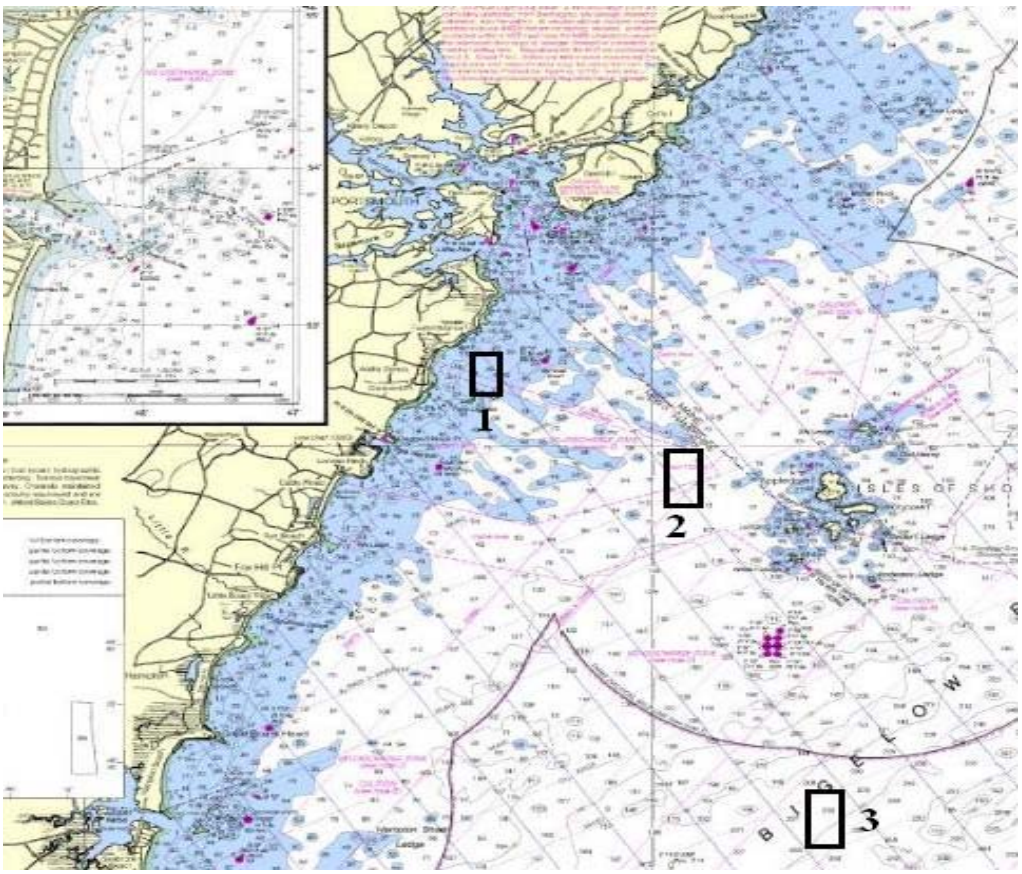


Figure 9. NOAA Chart 13278 highlighting testing locations. (1) Off Wallis Sands Beach, Rye NH ~45 FOW. (2) Between Portsmouth NH and Isles of Shoals ~120 FOW. (3) SE of Whaleback, ~8nm E of Hampton Harbor NH, ~240 FOW.

Throughout the testing a log was kept to ensure that any anomalies observed during testing were noted and considered during data processing, and to note any qualitative observations of each tow. Tow speed was initially monitored using GPS speed and was manually recorded. Engine RPMs were noted at the GSP speeds and kept constant throughout any given day of testing. The objective was to provide enough power to simulate a whale pulling the gear at ~2kts (personal comm. Scott Krauss) , by keeping the engine RPMs consistent throughout a day's testing.

Data reduction-Tow Test

The data for the tow test came in two forms, the data from the Star-Oddi loggers regarding depth (pressure) of the towed traps and the line tension data from the load cell. The Star-Oddi data were converted into a .txt file when they were downloaded from the loggers to the PC via the communication box at the end of each testing day. Each logger was assigned to measure depth (in meters) rather than pressure to eliminate a step in data processing. The data file contained a date and time stamp for each depth measurement. This time stamp made synchronizing events in the time series possible. Each logger had an offset that was corrected for by subtracting the average of the first 100 samples (when the logger was idle, and had not been submerged), thereby allowing the loggers to be 'zeroed'. Also, since the logger output measured pressure as a positive value, thereby corresponding to a positive depth, the negative value of these depths were used to better illustrate the elevations of the traps off the bottom when plotted.

This final set of depth numbers was then used to provide insight into the movement of the traps while under tow. The most important thing was to identify the sections of the data set in which the traps were being towed, then finding the average elevation of the trap relative to it's starting elevation (on the bottom). This was difficult in some instances, particularly with larger trawls, because some of the traps never came off of the bottom. It was necessary to make the procedure with which the data were treated consistent from data set to data set, to enable direct comparison.

First, it was necessary to identify each tow within the data set for each logger. This was done by correlating the start time for each run in the log notes with the presence of a change in the measurement of a logger (Figure 10, Table 1). This change in depth of the logger due to towing was more pronounced on the first trap in the series than the subsequent traps, in all cases, in trawls in shallower water and containing fewer traps, the data was more straightforward.

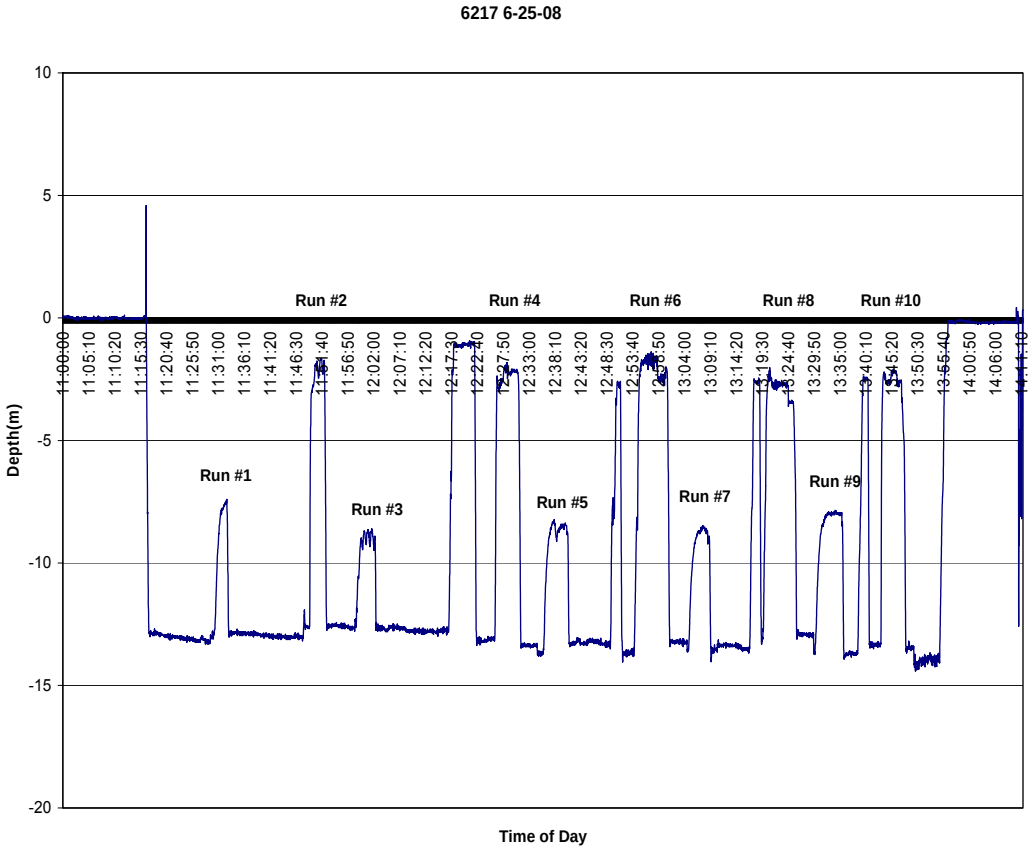


Figure 10. Sample Star-Odi plot showing the raw data Star-Odi logger (SN 6217) with labels corresponding to run numbers. Odd numbered runs were pulled with a long scope with this logger being the last in line out of 5, and even run numbers were pulled with the short scope, this logger was in the first trap in line.

Table 1. Star-Oddi logger data sample (SN 6217) of the last logger in a 5-trap-trawl on 6/25/08. This section of data shows the trap depth transition at the beginning of a tow test. Notice how the depth changes from being fairly consistent while the traps are on the bottom (~13m), to approaching the surface when the tow is started.

Time	Uncorrected depth(m)	Corrected depth(m)	Negative depth(m)
11:30:00	11.056	14.88	-13.09932817
11:30:02	11.056	14.88	-13.09932817
11:30:04	11.056	14.67	-12.88932817
11:30:06	11.025	14.61	-12.82932817
11:30:08	11.025	14.72	-12.93932817
11:30:10	11.025	14.72	-12.93932817
11:30:12	11.025	14.67	-12.88932817
11:30:14	11.025	14.51	-12.72932817
11:30:16	11.025	14.51	-12.72932817
11:30:18	11.056	14.51	-12.72932817
11:30:20	11.088	14.41	-12.62932817
11:30:22	11.088	14.15	-12.36932817
11:30:24	11.119	14.05	-12.26932817
11:30:26	11.182	13.95	-12.16932817
11:30:28	11.307	13.8	-12.01932817
11:30:30	11.526	13.45	-11.66932817
11:30:32	11.589	13.25	-11.46932817
11:30:34	11.682	13.1	-11.31932817
11:30:36	11.744	12.89	-11.10932817
11:30:38	11.807	12.69	-10.90932817
11:30:40	11.9	12.43	-10.64932817
11:30:42	11.993	12.28	-10.49932817
11:30:44	12.055	12.13	-10.34932817
11:30:46	12.117	11.93	-10.14932817
11:30:48	12.148	11.67	-9.889328165
11:30:50	12.179	11.51	-9.729328165
11:30:52	12.21	11.41	-9.629328165
11:30:54	12.241	11.31	-9.529328165
11:30:56	12.272	11.15	-9.369328165
11:30:58	12.272	11.05	-9.269328165
11:31:00	12.302	11	-9.219328165

Once these events were isolated, an average was taken of 30 consecutive data points at what was observed to be steady-state depth for the tow for the first trap in the trawl. Since the loggers were synched with respect to time, this time period could be used throughout the rest of the loggers to represent the average steady state of the trawl for the specific tow (Table 2). In addition to this average measurement of the elevation of the traps during the tow, a similar average of the pre-tow depth was gathered, again being consistent in time throughout the series

of loggers, to define the pre-tow bottom (Table 3). This was necessary to compare the elevation of the traps with respect to the pre-tow water depth.

Table 2. Finding pre-tow bottom depth. Star-Oddi logger data sample (SN 6217) of the last logger in a 5-trap-trawl on 6/25/08. This section of data shows the trap depth before the tow test. The value in red is the average of 30 samples (in bold).

Time	Uncorrected depth(m)	Corrected depth(m)	Negative depth(m)	
0.47771	10.962	14.82	**-13.03932817**	
0.47773	10.962	14.92	**-13.13932817**	
0.47775	10.962	14.87	**-13.08932817**	
0.47778	10.962	14.87	**-13.08932817**	
0.4778	10.962	14.87	**-13.08932817**	
0.47782	10.962	14.92	**-13.13932817**	
0.47785	10.962	14.92	**-13.13932817**	
0.47787	10.962	14.92	**-13.13932817**	
0.47789	10.962	14.92	**-13.13932817**	
0.47792	10.962	14.87	**-13.08932817**	
0.47794	10.962	14.92	**-13.13932817**	
0.47796	10.962	14.92	**-13.13932817**	
0.47799	10.962	14.87	**-13.08932817**	
0.47801	10.962	14.92	**-13.13932817**	
0.47803	10.962	14.92	**-13.13932817**	
0.47806	10.962	14.92	**-13.13932817**	
0.47808	10.962	15.08	**-13.29932817**	**-13.1645**
0.4781	10.962	14.92	**-13.13932817**	
0.47813	10.962	14.87	**-13.08932817**	
0.47815	10.962	15.03	**-13.24932817**	
0.47817	10.962	15.08	**-13.29932817**	
0.47819	10.962	14.97	**-13.18932817**	
0.47822	10.962	14.92	**-13.13932817**	
0.47824	10.962	15.03	**-13.24932817**	
0.47826	10.962	15.03	**-13.24932817**	
0.47829	10.962	14.92	**-13.13932817**	
0.47831	10.962	14.97	**-13.18932817**	
0.47833	10.962	15.03	**-13.24932817**	
0.47836	10.962	14.97	**-13.18932817**	
0.47838	10.962	15.03	**-13.24932817**	
0.4784	10.962	15.08	**-13.29932817**	

Table 3. Finding average steady state, trap depth. Star-Oddi logger data sample (SN 6217) of the last logger in a 5-trap-trawl on 6/25/08.

Time	Uncorrected depth(m)	Corrected depth(m)	Negative depth(m)	
11:31:34	12.672	9.67	**-7.889328165**	
11:31:36	12.672	9.61	**-7.829328165**	
11:31:38	12.703	9.77	**-7.989328165**	
11:31:40	12.703	9.61	**-7.829328165**	
11:31:42	12.703	9.61	**-7.829328165**	
11:31:44	12.733	9.56	**-7.779328165**	
11:31:46	12.764	9.62	**-7.839328165**	
11:31:48	12.764	9.62	**-7.839328165**	
11:31:50	12.764	9.57	**-7.789328165**	
11:31:52	12.764	9.57	**-7.789328165**	
11:31:54	12.795	9.62	**-7.839328165**	
11:31:56	12.795	9.52	**-7.739328165**	
11:31:58	12.795	9.52	**-7.739328165**	
11:32:00	12.795	9.52	**-7.739328165**	
11:32:02	12.795	9.52	**-7.739328165**	
11:32:04	12.795	9.52	**-7.739328165**	**-7.686896**
11:32:06	12.795	9.46	**-7.679328165**	
11:32:08	12.795	9.41	**-7.629328165**	
11:32:10	12.795	9.41	**-7.629328165**	
11:32:12	12.795	9.46	**-7.679328165**	
11:32:14	12.795	9.41	**-7.629328165**	
11:32:16	12.825	9.36	**-7.579328165**	
11:32:18	12.825	9.41	**-7.629328165**	
11:32:20	12.795	9.41	**-7.629328165**	
11:32:22	12.795	9.36	**-7.579328165**	
11:32:24	12.795	9.31	**-7.529328165**	
11:32:26	12.795	9.36	**-7.579328165**	
11:32:28	12.795	9.26	**-7.479328165**	
11:32:30	12.825	9.26	**-7.479328165**	
11:32:32	12.795	9.26	**-7.479328165**	
11:32:34	12.795	9.26	**-7.479328165**	

After producing the averages for both the bottom and trap elevation for the first trap in the tow, an Excel program was developed to utilize the time periods over which the values for trap depth were averaged, and find the averages for a different logger's output over the same time period. In the end, a value for the starting water depth, and the mean elevation for each trap (with a logger) was extracted. These data were then plotted using Excel (Figure 11).

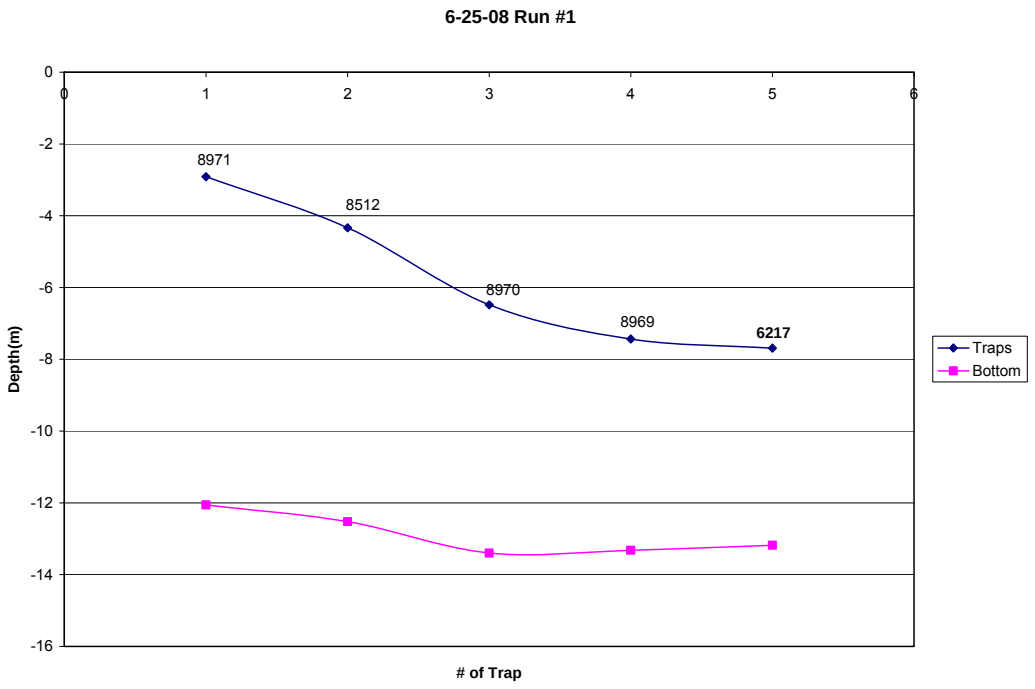


Figure 11. Sample trap elevation plot. Plot of run #1 on 6-25-08, using a long-scope end line. The blue line corresponds to the traps under tow, while the pink line denotes the starting bottom depth. The logger 6217, highlighted in red is the logger for which the sample data reduction was preformed for above.

The load cell data for the tow tests were processed using a Matlab program which focused on plotting the results. This code returned the average load under tow, the maximum load during the tow, and the TTC. The data were easier to handle as the LabView data acquisition and measurement were more direct.

Pilot Study

The data collected for the pilot study had two components. The initial threshold testing of the TTLC was necessary for comparison after field use. The data logs subsequently submitted by the volunteers were important to clarify the 'field use'. The TTC evaluation before and after use were quantitative assessments of the TTLC, while the data logs were more qualitative in nature. Before all of the TTLCs were given to fisherman, they were threshold tested as described previously. This ensured that each TTLCs was functioning properly, and also provided a TTC to compare the "used" units to after they were returned.

The log sheet was used to acquire information about the performance of the TTLCs from the point of view of the fishers, as well as provide some insight to the operating environment and conditions. The fishers were asked to fill out these sheets every time they hauled their TTLC-equipped gear, and fill in the matrix corresponding to each particular unit. This matrix contained selections for bottom type, depth of water, and “gap” distance (color showing).

When the TTLCs were returned by the fisherman after the first round of testing at sea, they were returned to the lab for testing to evaluate their performance compared to the initial threshold TTC values. This re-evaluation was done under the same conditions and using the same setup as the initial threshold testing. The blades in the TTLC were not changed for re-calibration as they are a critical component in the intended operation of the TTLC.

Table 3. TTLC Recalibration. Example of TTLC recalibration compared to original TTC data. The percent change refers to the increase in the TTC over the original calibration values. This re-calibration occurred after 10 hauls, without changing the blade.

TTLC #	**AA**	**AB**	**AC**	**AD**	**AE**	**AF**	**AG**	**AH**	**AI**	**AJ**
New (min)	6.53	5.36	5.55	7.53	7.86	5.10	10.44	10.76	7.15	5.33
Used (min)	11.97	14.32	6.32	16.32	23.42	7.28	16.08	16.39	15.00	10.27
%change	**83.16**	**166.98**	**13.73**	**116.83**	**197.99**	**42.81**	**53.95**	**52.36**	**109.79**	**92.50**

RESULTS

The results from all components of this study are presented here. These results are presented here in a format which is intended to help draw conclusions about the TTLC. The figures and tables are therefore summary in character. The results of the tow test, pilot study, and lab testing necessary to understand the operation of the TTLC are presented. Each component of the study is presented separately beginning with the tow experiments, followed by the pilot study. Details pertinent to each component are presented along with the data to help clarify the results.

Tow Test

Tow testing data were collected, with varying water depth, bottom type, end line scope, and number of traps. A summary of the number of data sets collected in terms of the number of traps and the depth of water can be seen in Table 4.

Table 4. Tow Summary. The number of tows completed at each water depth and for each length (number of traps) trawl.

Number of traps	~45'	~120'	~240'	Total
5	10	12	0	22
10	0	10	12	22
20	0	9	0	9
Total	14	31	12	**53**

The choice to do this distribution of the tests was to reflect fishing effort in each depth regime. This required varying the number of traps in a trawl, water depth, and end line scope.

The data extracted from the Star-Oddi loggers were reduced into plots which showed the average elevation of the traps while under tow. These data were then broken down into two sets within each testing day- the tows utilizing a long end line and those using a short end line. The following figures show the trap depth locations and hence a ‘trawl profile’ during the steady part of the tow.

The profiles for the long and short scope end lines are shown along with an average bottom.

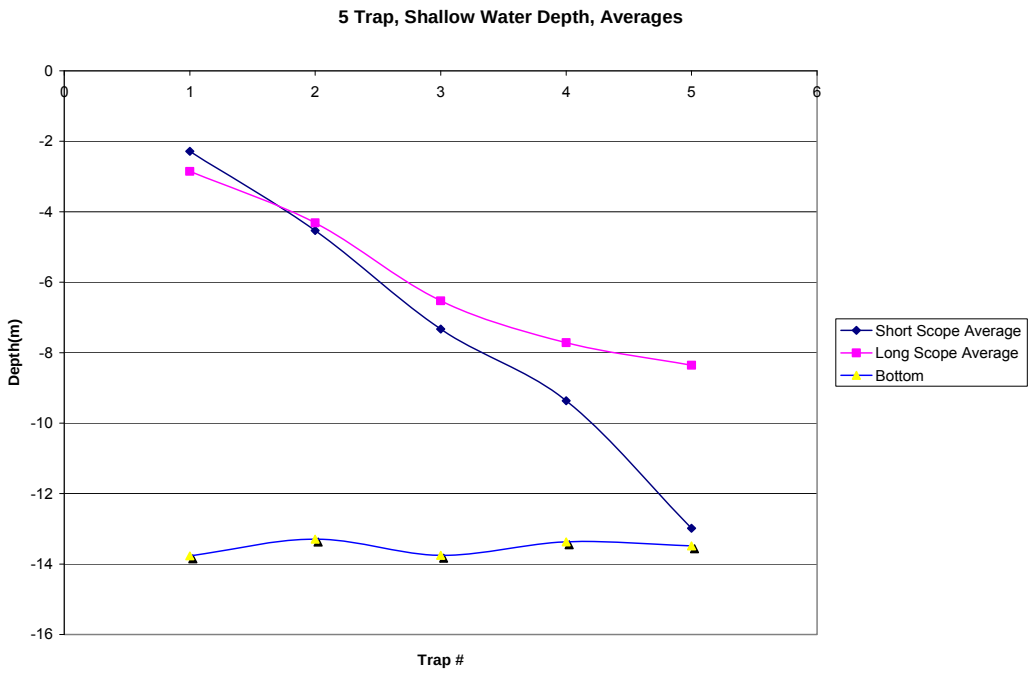


Figure 12. Five trap shallow water averages. This plot shows the average of all of the tow tests made with five traps in shallow water depth.

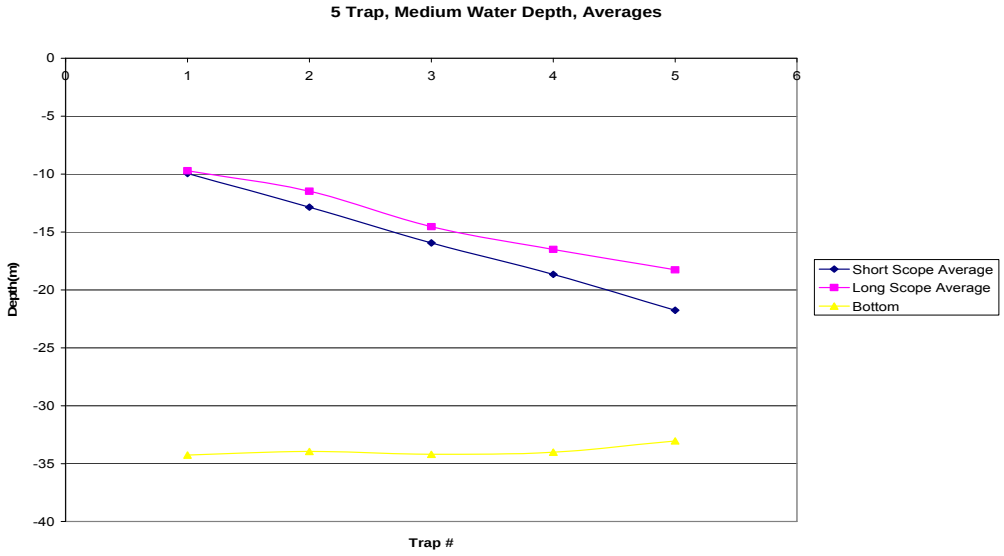


Figure 13. Five trap medium water averages. This plot shows the average of all of the tow tests made with five traps in medium water depth.

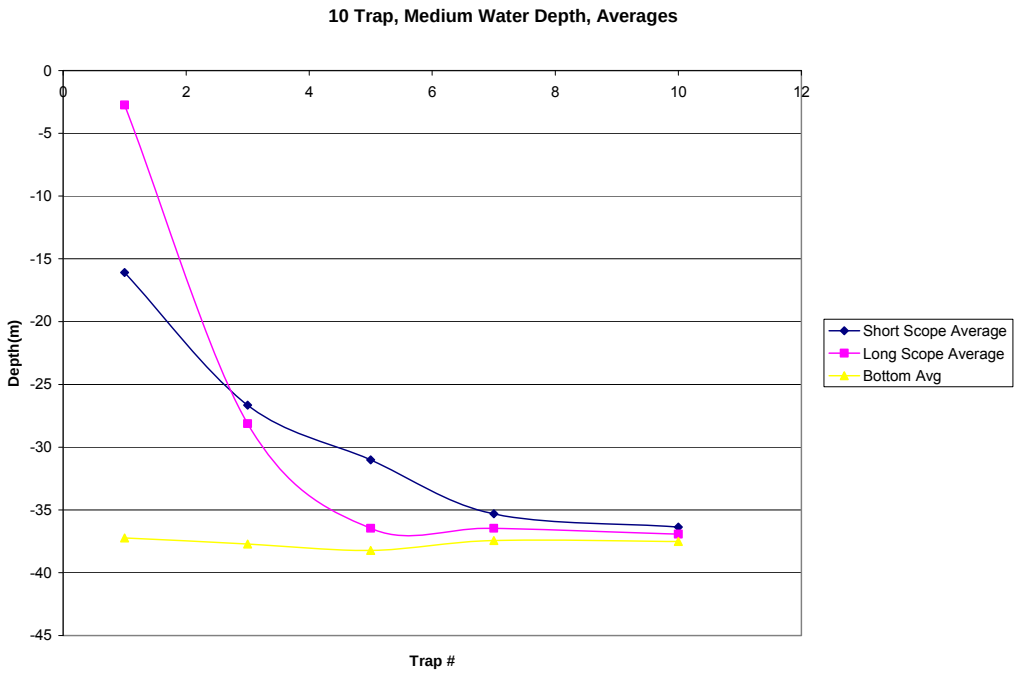


Figure 14. Ten trap medium water depth averages. This plot shows the average of all of the tow tests made with ten traps in medium water depth.

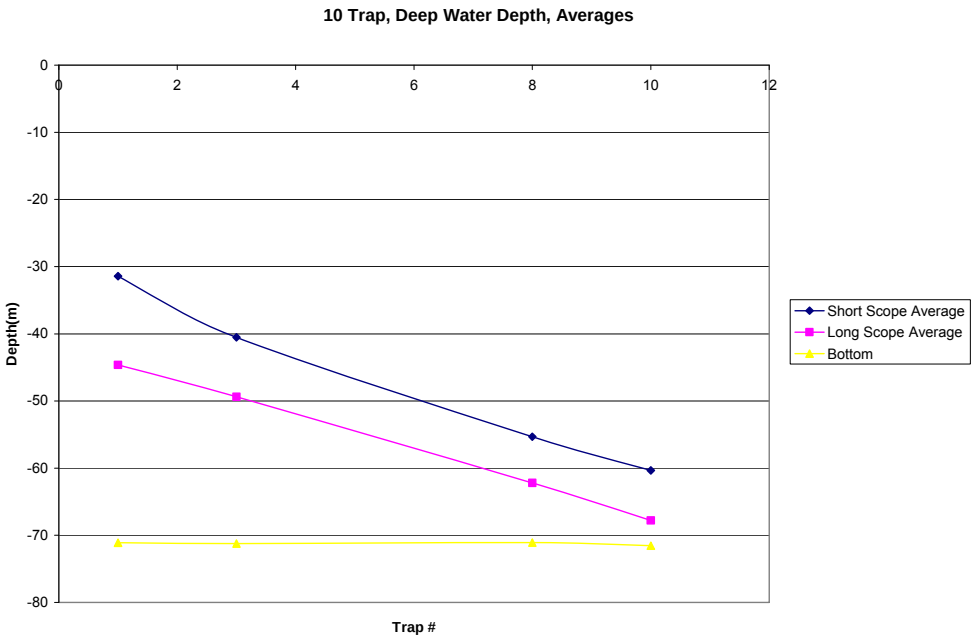


Figure 15. Ten trap deep water averages. This plot shows the average of all of the tow tests made with ten traps in deep water depth.

The 20 trap trawls were not productive. The load on the boat did not allow for enough time for the traps to reach a steady state. The engine overheated in

one attempt. There were entanglements during three other attempts. There were load data from the end line recorded in these attempts as reported below.

Load Data

Load cell data were taken from the Omegadyne 2.5K strain gage load cell, rigged from the gin pole on the Jesse B. A representative plot of load vs. time is shown in Figure 16. The complete load set of load data plots is in the Appendix. This loading represents the tension in the end line (towing hawser), which represents both the force on the whale of the trailing gear, as well as the force on the TTLC at the bottom of the end line. Tables 5-7 show a summary of the load results.

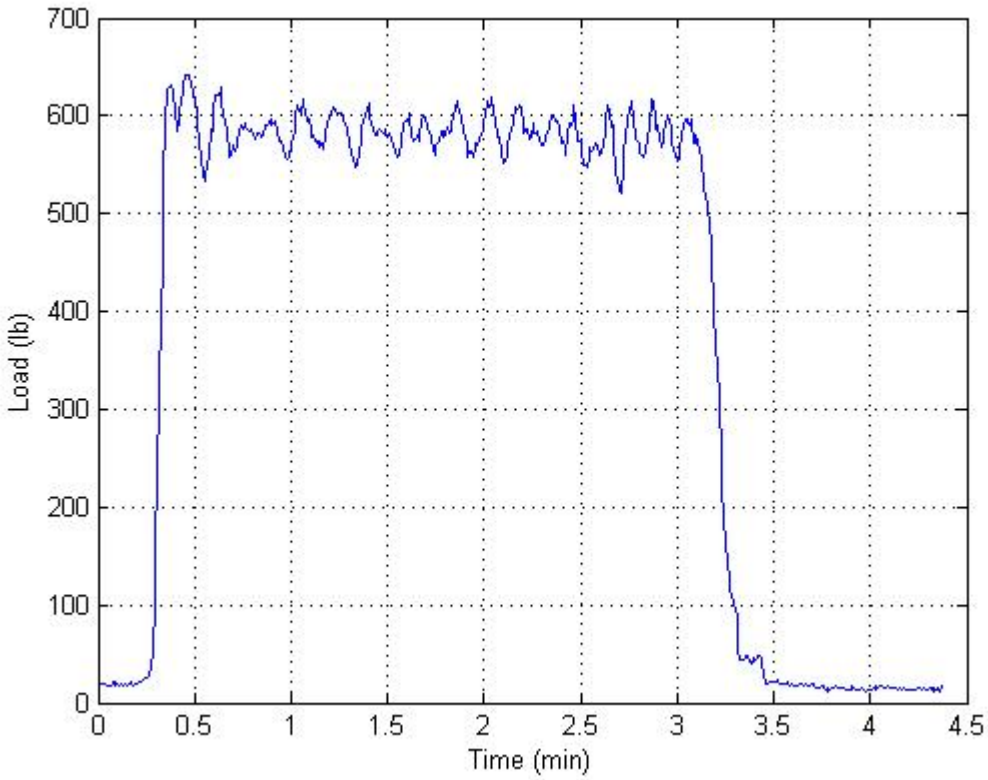


Figure 16. A representative load vs. time plot from a trawl tow with five traps.

Table 5. Load cell and TTC data for all five-trap trawl tow tests. The data are the average loads and the maximum load during the tow. This average load was taken from the start of the tow until the tow was finished or the TTLC was cut.

6/25/2008 (5 traps, shallow water)

run	1	2	3	4	5	6	7	8	9	10
avg(lbs)	565.8	572.2	564.6	527.0	570.8	570.0	587.5	491.5	581.4	492.8
max(lbs)	633.3	642.5	654.6	666.6	722.2	742.3	746.7	711.8	741.6	796.6
ttc(min)	3.0	no ttlc	4.2	4.5	5.1	6.0	4.4	5.7	5.8	4.6

6/27/2008 (5 traps, medium water)

run	1	2	3	4	5	6	7	8
avg(lbs)	486.4	433.5	495.8	451.2	451.2	502.2	495.7	451.9
max(lbs)	707.0	764.2	633.9	559.8	596.7	562.4	646.6	575.4
ttc(min)	6.4	10.1	7.2	blade	8.0	blade	5.5	blade

7/9/2008 (5 traps, shallow water)

run	1	2	3	4
avg(lbs)	372.1	404.4	439.2	489.1
max(lbs)	468.6	482.3	546.5	625.6
ttc(min)	6.7	tangle	7.9	18.2

Table 6. Load cell and TTC data for all 10-trap trawl tow tests. The data are the average and the maximum loads during the tow. This average load was taken from the start of the tow until the tow was finished or the TTLC was cut.

7/2/2008 (10 traps, medium water)

run	1	2	3	4	5	6	7	8	9	10
avg(lbs)	508.8	628.1	572.6	537.6	541.8	595.7	548.6	629.8	611.3	626.8
max(lbs)	693.3	1119.2	837.0	1016.9	896.7	905.3	908.2	803.9	935.8	1056.9
ttc(min)	6.5	4.6	5.7	6.1	6.2	6.1	6.2	4.8	5.3	5.0

7/16/2008 (10 traps, deep water)

run	1	2	3	4	5	6	7	8
avg(lbs)	590.2	531.0	540.1	585.5	584.7	539.4	604.1	526.4
max(lbs)	795.3	648.2	688.2	931.0	708.9	789.6	1003.2	731.5
ttc(min)	11.9	11.5	6.0	12.5	5.0	15.0	11.3	broke line

7/17/2008 (10 traps, deep water)

run	1	2	3	4
avg(lbs)	561.8	603.4	605.1	675.8
max(lbs)	713.7	774.0	983.5	1045.5
ttc(min)	8.0	6.2	17.3	15.2

Table 7. Load cell and TTC data for all 20-trap trawl tow tests. The data are the average and the maximum load during the tow. This average load was taken from the start of the tow until the tow was finished or the TTLC was cut.

8/13/2008 (20 traps, medium water)

run	1	2	3	4	5	6	7	8	9
avg(lbs)	947.4	1015.3	1046.8	929.7	874.9	937.3	947.0	830.4	673.2
max(lbs)	1251.7	1338.5	1212.0	1438.3	1138.6	1221.8	1372.2	1143.7	1219.0
ttc(min)	no record	11.4	7.5	engine	7.1	2.5	tangle	tangle	tangle

Pilot Study

There were five boats originally participating in the pilot study. Three of the five provided results and were great volunteers, while one boat decided after a bit to withdraw. There was one boat which participated late in the study and the TTLC from this boat have vanished for reasons unknown. The results from the logs are presented here along with the available revaluation of the TTC. Fishing effort during the pilot study time frame was reduced as the price of fuel for the boats increased substantially while the price of lobster went down. These are the conditions which evidently and understandably lead to reduced fishing.

It was intended to meet with the participants after the study was completed. The intention was to use this opportunity to obtain feedback from the fishers. The fishers provided all the feedback available to Tim Pickett whenever he talked with them. He had many conversations with them and it was apparent that new feedback would not be forthcoming. It is our belief that this is because the fishers had no difficulties using the TTLC with the exception of the one boat noted below.

F/V *Rough Times*

Ten TTLCs (SN AA through AJ) were distributed to the *Rough Times* in midsummer 2008. The *Rough Times* fishes out of Portsmouth NH and participated throughout the Fall of 2008 and Spring of 2009. The 10 TTLCs were fished on one end line of 10 trawls which were 10 trap trawls except one. These TTLCs were rigged as shown previously at the bottom of the end line. Only one TTLC was used per trawl, with the other end line remaining intact, incase of TTLC malfunction, enabling the gear to be hauled in a standard method as well.

After spending approximately one month exposed to fishing conditions and completing 10 hauls of the test gear using the TTLCs, as prescribed, and filling out the provided log sheets, the TTLCs were returned to UNH for re-calibration using the same setup described earlier. The data for this re-evaluation can be found in Table 8, The TTLCs were then given back to Mr. Adamaitis for another iteration of testing beginning in the late fall of 2008 and continuing the spring of 2009, after the gear had been hauled out for the winter.

In the late Fall 2009 these TTLC were removed from active fishing and were again returned to UNH in January 2010 for another evaluation of their operation. These results are also in Table 8 in the row designated 'used 2'.

Table 8. F/V *Rough Times* TTC data after two trial periods.

TTLC ID	**AA**	**AB**	**AC**	**AD**	**AE**	**AF**	**AG**	**AH**	**AI**	**AJ**
New (min)	6.5	5.4	5.6	7.5	7.9	5.1	10.4	10.8	7.2	5.3
Used 1 (min)	12.0	14.3	6.3	16.3	23.4	7.3	16.1	16.4	15.0	10.3
Used 2 (min)	11.6	9.1	7.4	18.1	26.4	7.1	16.2	13.3	20.8	11.0

At the conclusion of the testing, the captain expressed no concerns about the durability of the TTLC. He had no significant problems with hauling his gear other than "getting used" to using a jumper to bypass the TTLC around the block during hauling. Once he became familiar with the procedure, he claimed that fishing with the TTLCs was not unsafe, and didn't add significant time to his hauling routine, which were the major of concerns for many fishers when previously shown the TTLC.

The only concern in terms about the TTLC expressed by the captain was that the line would chafe around the attachment points of the TTLC over time, thereby weakening the line and potentially allowing it to break during a storm or in the hauling process. He suggests that since the TTLC sinks, it could roll around the bottom, thereby chafing the line at the attachment points. This bottom contact – abrasion concern is voice by many fishers about sinking ground lines. When the TTLC sinks, it could be in a situation which would allow the inclusion of sediment in the line, thereby abrading the line as a whole when cyclically loaded, and working the grains of sediment against the individual strands of line. His suggestion to resolve the situation would be to somehow either float the TTLC or to make the TTLC itself buoyant to eliminate the bottom's interaction with the line. He also noted that the TTLC as is could be used effectively if the user took note of any chafing of the line and simply advanced the line through the TTLC periodically and eliminated the chafed portion of line.

F/V Island Lady

Ten TTLCs (SN AK through AT) were given to the *Island Lady* out of Portsmouth NH, in September of 2008 and fished through November of 2008 for a total of 10 hauls of the gear. The TTLCs were rigged as suggested. The captain expressed no concern with the fishability or durability of the TTLCs he was given. Table 4.6 contains the return data for the first return of the TTLCs' after 10 hauls. The *Island Lady* did not participate in the pilot study beyond this initial deployment.

Table 9. F/V *Island Lady* TTC data after one trial period

TTLC ID	**AK**	**AL**	**AM**	**AN**	**AO**	**AP**	**AQ**	**AR**	**AS**	**AT**
New (min)	7.5	5.3	6.0	12.7	9.3	6.8	7.0	3.6	8.3	4.2
Used (min)	20.7	21.9	16.0	25.0	11.8	16.4	12.3	6.4	21.7	6.1

F/V *Patty-B*

Ten TTLCs were given to the *Patty-B* in September of 2008 for testing during the late fall/ winter of 2008. The units were tested throughout the fall and winter, and were returned in the spring of 2009. Unfortunately, the TTLCs were not rigged as they were intended to be used, but instead, rigged beneath the buoy as if they were a weak link. This was unfortunate from the standpoint of assessing the hauling strategies employed as there was no need to jump the block with the TTLC while hauling. However the amount of exposure time to the ocean elements, while having also been exposed during the winter makes these data interesting.

Table 10. *Patty- B* TTC data. These TTLC were left on the bottom over the winter and were only used when testing in the laboratory

TTLC #	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
New (min)	-	12.3	15.3	11.75	10.4	11.98	10.8	16.9	12.9	16.4
Used (min)	-	13.26	22.3	10.6	13.9	26.49	17.9	13.25	13.6	23.4

F/V *Patricia Lynn*

Ten TTLCs were given to the *Patricia Lynn* in July of 2009 for testing during the summer of 2009 for 10 hauls. The rigging used on this vessel for the TTLC is unlike all of the other participants in the study. The TTLC was used without using a jumper line beneath the TTLC to bypass the TTLC around the block. Instead the TTLC is manually pulled around the block. The captain felt it was unnecessary to install a jumper, and experienced no problems. These are the elusive TTLC's which were not available for reevaluation, still the captain's comments to Tim Pickett about how he rigged and fished the TTLC are quite interesting, especially in the comparison to the last boat.

The last boat:

Ten TTLCs were given to a fisher from Maine in late August 2008 to be fished for 10 hauls during the fall season aboard his vessel. When the units were delivered he was informed about the suggested method of rigging and hauling the TTLCs, and seemed confident that this testing of the units would go off without a hitch. All the requisite contact information (email and phone number) was provided in case there was a problem with the testing. After several months, when other participants had returned the TTLC for reevaluation contact was made with the captain via e-mail, and later phone. The captain provided information that he had fished one TTLC for one haul back and deemed the device "Unsafe due to having to jump the block, especially for a fisherman who fishes alone". The units were finally returned on February 6, 2009, and were in unused condition. Also, the log sheets provided were absent, and were substituted with other information not pertinent to this study. This person should not be contacted for any future studies of this nature.

Tow Test Analysis

The objective of the tow tests was to understand the behavior of lobster gear while being towed by an entangled, traveling whale. The quantitative data collected were in the form of pressure transducer data to measure the depth of

the traps relative to the surface, and in turn their height off the bottom while under tow, and load cell data to both quantify the load felt by the animal due to the ensnaring gear, as well as providing a simple way of identifying the TTC of the TTLC.

Pressure Transducer (Trap Elevation) Analysis

Of the 7 days at sea testing, two were completed using only four of the five because one of the transducers (SN 8970) was lost during one of those days. However, the remaining four transducers were intact and recording reliably. A replacement Star-Oddi was obtained to complete the testing. One of the variables in this test was the dependence of the scope of the end line on the trawl elevation profile while under tow. It was found that the scope of the end line changed the depth profiles of the traps, however differently as the depth and number of traps changed.

For the five trap trawl tows in shallow water, the trawls towed from a shorter-scoped end line tended more towards the bottom than those with the longer scope (Figure 12). In this case the difference between the averages for the shallow water testing and the deep water testing were also quite dramatic. In the shallow water test, the long-scoped had all five traps consistently off of the bottom and the profile of the traps was fairly smooth, with traps 3, 4, and 5, on average, lying within two meters of each other in the water column. However, for the short scoped end line tests in the same water depth, the profile is quite different, with the traps all tending more to the bottom in a more linear fashion, with traps 3, 4, and 5 not leveling out like they did in the long scope tows.

In the medium water depth (Figure 13), the trap profiles for both the short and long scoped end lines more closely resembled the shallow water profile of the long scope tests. Again, the short scoped profile tended to be generally deeper than that of the long scope profiles, but not nearly as drastic as those for the shallow water tests, but the traps, as a whole were deeper than that for the shallow water tests. All of the 5 trap trawl tests had all 5 traps in the trawl completely off the bottom with the exception of a few of the shallow water, short

scope tows, in which case the 5th trap in line sometimes was on the bottom while under tow.

In terms of the 10 trap trawls, in the medium water depth (Figure 14), both the long and short scoped tows tended near the bottom with traps 3-10 consistently within 10m of the bottom. The most noticeable of the differences between the long and short scoped tows for the medium water depth were that the long scoped tows had the first two traps significantly higher in the water column than the short scoped tows, the 3rd trap was at the same relative elevation, but subsequent traps tended more towards the bottom, until the 7th-10th traps were both the long and short scoped data sets showed the traps at or near the bottom.

The 10 trap deep water tows (Figure 15) were significantly different than the 10 trap tows in medium water depth. The profiles were less dramatic than the medium water depth, and were much like the profiles of the 5 trap trawl in medium water depth. However the short scoped tows were consistently higher off the bottom than the long scope tows.

Tow Test- Sources of Error

There were unforeseen sources of error associated with experimental work offshore that need to be qualitatively taken into consideration while analyzing the data. The actual velocities of the tows were approximate and taken as the average speed over ground (SOG) from the GPS on the *Jesse B*. This speed was simply noted periodically throughout the tow and was written down in the log for the tow. Engine speed (RPMs) was noted in relation to the SOG and the rpm was easier to maintain over the course of a tow. These precautions were taken to try and eliminate speed as a variable, and keep the speed consistent at 2-3 knots for each test. This was difficult to regulate with extreme accuracy because of the tradeoff between basing the test on SOG or on engine RPMs. Since the engine RPMs were the easiest to regulate, and provided a consistent pulling force, rather than speed, the engine RPM were held consistent for a series of tests. Another concern with using SOG rather than engine RPMs is that SOG doesn't take into consideration the influence of ocean currents. The

inclusion of the local currents during a test is important because it influences the relative velocity of the flow field around the traps, and since the traps are supposed to be towed at 2-3 knots, the exclusion of ocean currents on the results could not be neglected, and hence, SOG becomes an inaccurate matrix of measuring speed.

Even with using engine RPMs as a way of quantifying and keeping tests consistent, there still is some uncertainty as to the consistency of the results in terms of the actual velocity of the flow field encountered by the traps. This discrepancy would influence not only the elevation profile of the traps, but would influence the loading data as well. This could be remedied in future tow tests by employing an ADCP while conducting the tow tests, as well as a GPS that could record position and SOG in real time. This would allow for a correlation between the current magnitude, and direction, which could correct the ship's SOG into a real velocity felt by the traps, thereby allowing for more thorough interpretation of the trap profile and loading data.

Sea state and weather were noted daily in the log, and were fairly consistent, as only days with calm sea conditions were used for testing, this was done to ensure the accuracy of the data, as well as to ensure the safety of the vessel and equipment.

The largest discrepancy in the entire test was with the data for the 20 trap trawl test. Since only five pressure transducers were available, it was decided to place the transducers in the first 10 traps, in the same configuration as they would be in a 10 trap trawl. The idea behind this type of configuration, is that the trawl could be pulled first by the end with the transducers closer to the tow line, and then again with the transducers being far away from the end line. This could be done using both a short and long scoped end line, with the end result being appearing as though 10 transducers had been distributed throughout the trawl. The results, however, were difficult to interpret for a myriad of reasons.

Another source of error was that the *Jesse B* could not, at times, muster enough power to move the entire trawl, without "stalling out" (propeller moving, but no forward progress being made), or overheating the keel-cooled engine and

transmission. Also, at some point during the test, the towed trawl became ensnared in some unmarked, abandoned, lobster gear. This was an added variable that undoubtedly affected the results, as the exact time of the entanglement in the abandoned gear was unknown, and the extent to its effect on the test remains unknown. However, this event could simulate what could actually happen if a whale became entangled in a trawl of lobster gear, that is an ensnaring trawl gathering additional gear as it was being towed. The TTLC in this case still preformed as designed, and cut the end line after a period of time in all four instances in which the TTLC was used.

Tow Test- TTLC Performance

Overall, the TTLCs preformed as designed, with cuts occurring on the majority of tests, within their calibrated timeframe. The largest deviation in time consistency seemed to stem from the blades in the TTLC becoming chipped or otherwise damaged (edge rolled over, etc.) due to repeated cutting. In a real scenario, however, the blade in the TTLC would be in pristine condition because repeated cuts would not occur under operating conditions, as they did throughout the tow testing. A more in-depth look at the contribution of blade fatigue on the variance of the time to cut was investigated as part of the pilot study section.

Pilot Study

In terms of the consistency of the calibration results, a controlled testing procedure was strictly followed, and kept consistent throughout the calibrations of the TTLCs throughout the pilot study. There were some discrepancies in TTC between the original TTC and the “used” (after 10 hauls of exposure) TTC. Observing the data from Tables 8, 9 and 10 it is apparent that most of the TTLC yielded a longer TTC after being deployed. The discrepancies were thought to be the result of blade quality and variability. To investigate this five TTLC were randomly selected from the final 19 which were tested in January 2010. The TTC were initially measured with the ‘old’ blades in the TTLC and a value was recorded. These old blades were subsequently changed in the five and the TTC reevaluated. Four of the five had a TTC which was approximately half the value of the TTC with the old blade, see Table 11. This indicates that the inner

workings of the TTLC are performing as designed and that the difficulty is with the blade quality and integrity. This is a situation which can be readily remedied with a blade designed explicitly for the TTLC versus just using what is available.

Table 11. Summary of TTC results for the five randomly selected TTLC with new blades. All TTC values are in minutes.

TTLC ID	TTC 0	TTC 1	TTC 2	TTC New Blade
02	5.4	14.3	9.00	7.62
09	7.2	15.0	20.8	12.53
43	15.3	22.3		11.95
46	11.98	26.49		13.24
50	16.4	23.4		10.22

Pilot Study- Fisherman feedback analysis

The qualitative feedback from the fisherman participating in the pilot study was quite promising in terms of their ability to effectively fish using the TTLC. There were, however several comments expressed by the fisherman concerning improvements that could be made to make the units be more “fishable”. One general concern, across the board was with the fact that the units sink when deployed, thereby allowing for the units and their connecting lines to interact with the bottom. This is of particular concern when fishing on hard bottom because the TTLC could roll across the bottom and be lodged between rocks, making retrieval of the gear difficult. Several of the fisherman indicated that adding some type of buoyant component to the TTLC, or by making the unit itself buoyant would be preferable over the existing design and deployment. Compounding the issue of the sinking TTLC is the fact that they are round and could roll across the bottom, increasing its ability to hang on the bottom. A suggested fix to this problem would be to have the plastic housing of the TTLC have square edges, which would make the units less likely to roll along the bottom, and therefore less likely to find a hang.

Further Investigation/Lab Work

After performing the tow tests on the Jesse B, it was apparent that additional insight into the mechanics of the towed traps was needed to better correlate the contributions of each individual component of the gear in tow to better understand the trap profiles and end line loading data generated during the tow test.

Since the end line loading at steady state (traps all being off the bottom) is essentially a measure of the drag force of the gear due to the oncoming water (tow) velocity. The two factors that contribute -to this hydrodynamic drag are the lines (both the end line and ground line) and the traps. Equation 6.1 (Fridman, 1986) estimates the drag force on a towed line in terms of water (tow) velocity, line diameter, line length, and angle of attack.

$$R_x = C_x * L * D * q \qquad (1)$$

Where,

$$q = \frac{\rho * V^2}{2} \qquad (2)$$

Where R_x is the line drag force, C_x is the coefficient of drag, L and D are the length and diameter of the line, respectively, and q is the hydrodynamic stagnation pressure. C_x is dependent on the angle of attack (α) between the line and the approaching water velocity. Fridman (1986), relates C_x and α in Table 12 based upon data collected using 16mm steel rope. This estimation also neglects the dependence of C_x on the magnitude of the Reynolds number, however the table provided allows for baseline estimate for C_x.

Since C_x is dependent on the angle of attack of the line in the flow, and the angle of each line in each test was highly variable, even within data sets (particularly between traps), a Matlab code was written to extract the angle of the both the end line and the ground line in between traps. The code line_drag_calc.m loads the average trap elevation data from a set of tow tests, and calculates α of each line segment in the trawl. Figure 17 shows how the code extracts the angles (α1,α2) from lengths (L1,L2) and trap depths (D1, D2), using

simple trigonometry. The code then interpolates the data from Table 12 for a value of C_x, and uses this value in equation (1) to calculate the drag for each segment of line. The sum of these line segment drags is the net drag on the whole trawl due to the line.

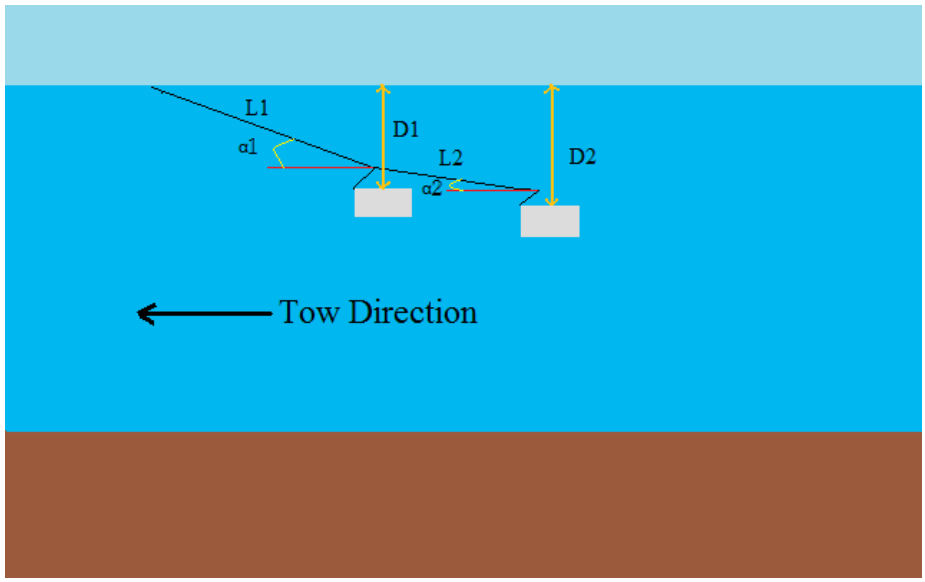


Figure 17. Computer model definition. Diagram of tow setup showing resultant angles (α1,α2) as a relation to lengths (L1,L2) and trap depths (D1, D2) relative to the tow direction which is opposite of the incident flow. Since the angle of the line connecting each trap as well as the angle of both end lines differ from each other, these angles need to be calculated independently for each line segment, yielding a different drag coefficient and therefore a different drag force for each line segment.

Table 12. Cx dependence on α (Fridman, 1986)

α(deg)	C_x	α(deg)	C_x
0	0.12	50	0.70
10	0.20	60	0.90
20	0.32	70	1.12
30	0.41	80	1.25
40	0.56	90	1.30

Since D remained constant for all tests, and L only varied with changing trap configurations, only C_x and q were variable from test to test, in terms of the drag force contributions of the line. Once the code extracted these individual drag

contributions of the line segments of the trawls for each average testing scenario, it could be compared to the measured values for line tension in the tow to provide insight as to the contribution of line drag to the total tension value in the end line. This could then be combined with an analytical estimation of the amount of drag force exerted by a trap to form a complete model of the end line tension in terms of the static (weight) and dynamic (drag) contributions of the line and the traps.

However, due to the complex geometry of a lobster trap, finding a generic value for a drag coefficient (C_{xtrap}) from a chart or a table was difficult. The simplest and most accurate method for evaluating C_{xtrap} of the trap was to perform a series of tow tests at a controlled velocity to back out a consistent value for C_{xtrap}. Equation (3) is used to back out this C_{xtrap} given the measured drag force via a load cell in a towing experiment, projected area of the trap, known water density, and tow velocity.

$$R_x = \frac{1}{2} C_{xtrap} * \rho * A * V^2 \qquad (3)$$

Where R_x is the resultant drag force of the trap being towed, C_{xtrap} is the drag coefficient of the trap, ρ is the density of water, A is the projected area of the trap exposed to the flow, and V is the tow (fluid) velocity. One interesting variable in this equation, particularly in how it applies to this specific problem is the definition of the projected area A. To simplify the calculation it was assumed that the front face of the trap comprised the projected area normal to the flow. This area was chosen because of the dominance of the contribution of the parallel (to the flow) faces of the trap, and also because the inclusion of the trailing face of the trap would have to include the presence of shadowing from the leading face of the trap, which is exceedingly computationally intensive for this investigation. Then C_{xtrap} could be extracted using the known towing velocities, the constant water density, the constant projected area of the trap, and the measured value of the resultant drag force.

Tow Tank Test

The UNH tow tank consists of a 100'x12'x8' deep tank with a cable driven tow carriage to which the towed structure is attached. In this case, since hydrodynamic drag was the desired quantity to be measured, the drag force needed to be isolated so it could be directly measured with the load cell attached to the carriage. The setup was adapted from Risso (2007) in which the towing apparatus was used to test net panels for scaling use in aquaculture applications. Similarly, in the case of the net panels, hydrodynamic drag was the desired quantity, and was measured using a swiveling mount of the net panel to allow for lateral movement in the direction of the flow (drag) while inhibiting vertical movement of the panel (lift), to measure the purest possible component of the drag force.

The setup for this experiment consisted of two vertical, and one horizontal sections of 80/20 Inc. aluminum stock attached to a swiveling assembly made of 1.5" pipe (Figure18). This mount was attached to the trailing side of the carriage, while an aluminum beam holding the load cell was attached to the leading side of the carriage. In this case, once a bridle line was lead from the trap to the load cell, and a tow was started, the trap would swivel on its mount about the axis of the horizontal pipe, allowing the load cell to record the horizontal resistivity of the trap against the oncoming flow (hydrodynamic drag). The load cell that was used was a Sentran 50lb S-beam load cell with an output voltage capacity of 0-10V and was captured using the in-house Labview software on the tow carriage computer (Figure 19). The data was then processed in Matlab using steady_state_v3.m to return the average loading and to plot the load cell output.

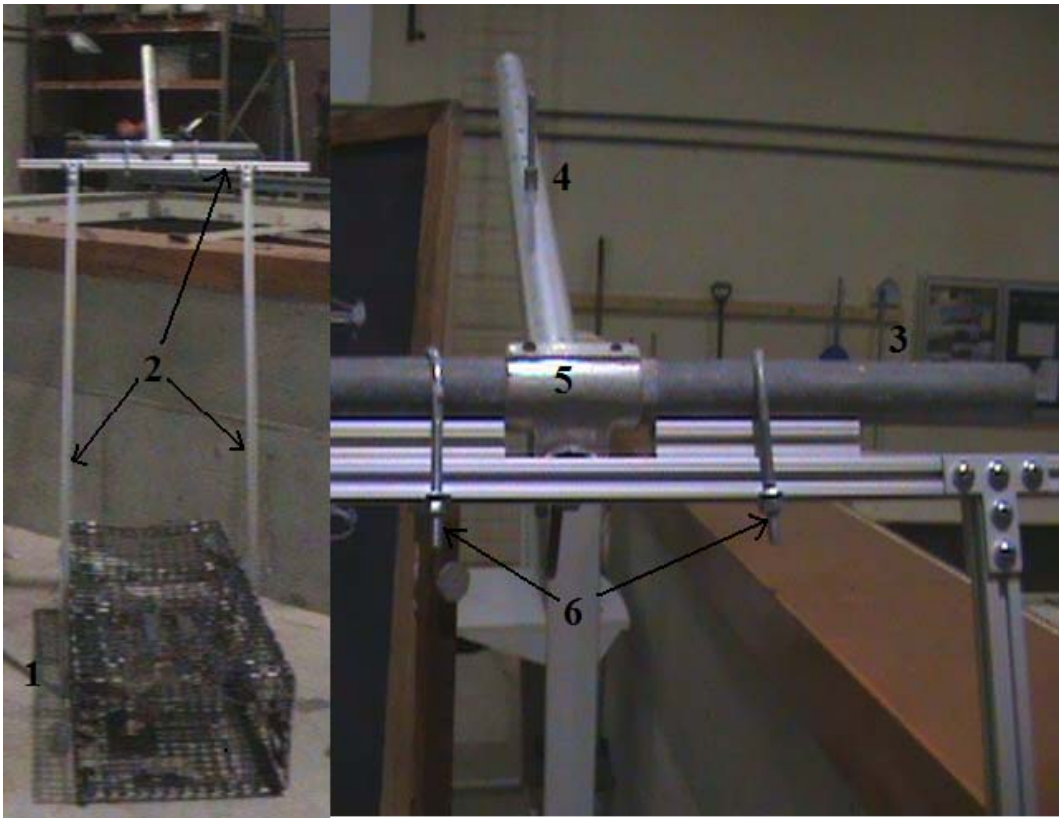


Figure 18. Tow carriage mount. Photos of mounting apparatus used to perform tow test in UNH tow tank to extract drag data. The components of the mount are as follows: (1) Standard 4', 3 brick lobster trap. (2) 80/20 extruded aluminum stock and connectors used for uprights and cross member. (3)1.5" OD steel pipe. (4)1.5" OD aluminum pipe used to attach the mount to the tow carriage; holes were added to provide elevation adjustment. (5) Pipe connection with ID slightly higher than the OD of the vertical and horizontal pipes. This connector was tightened on the vertical pipe, and left loose on the horizontal pipe, allowing the mount to swivel about the axis of the horizontal pipe. (6) U-bolts and 80/20 spacers attached the horizontal pipe to the 80/20 cross member, while allowing for the swiveling pipe connection to rotate.

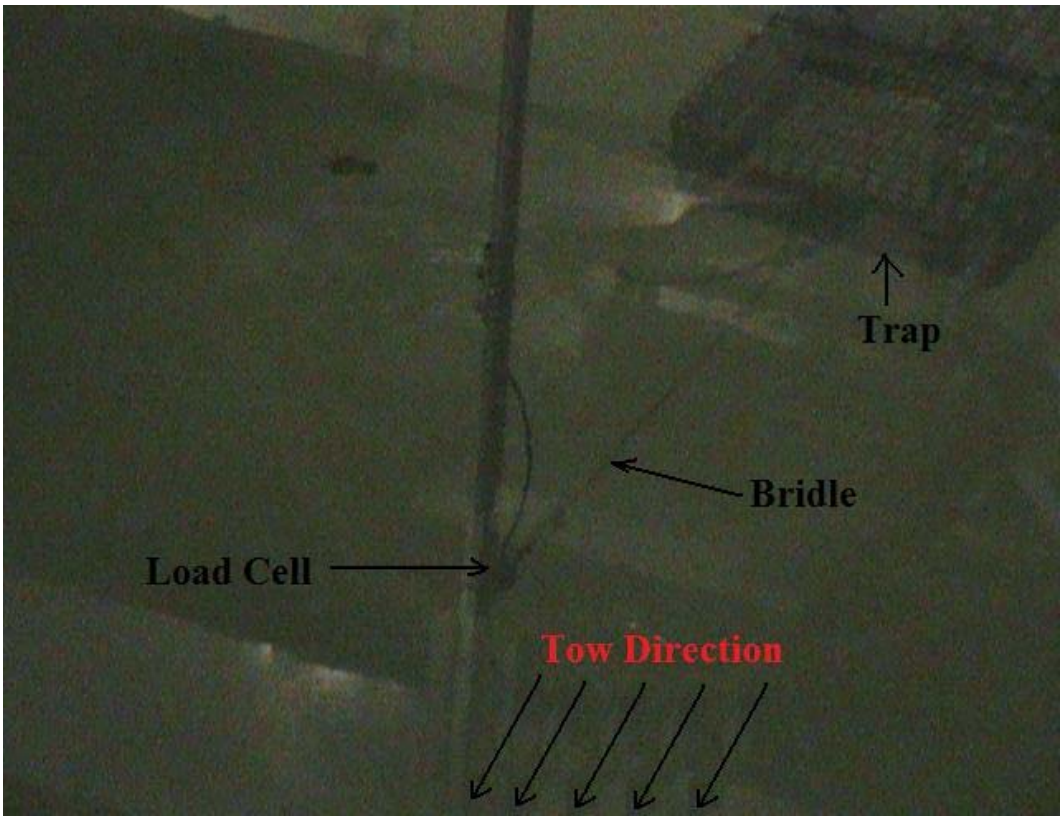


Figure 19. Load cell and bridle. The towing setup attached to the tow carriage, with the load cell attached to a vertical beam aligned with the leading edge of the trap. A bridle is rigged from the outside edges of the trap, and reduced to one line leading to the load cell.

Results of the model

Data were collected using the computer aboard the tow carriage, which was controlled using the computer on the control station above the tow tank. Data that were collected were the output voltage of the load cell vs. elapsed time for three different velocities (0.5, 0.75, and 1m/s), with three repetitions at each velocity. This data was plotted (Figure 20) using Excel and a polynomial equation was fit to the data to enable a prediction for drag force at velocities different than those completed in the test.

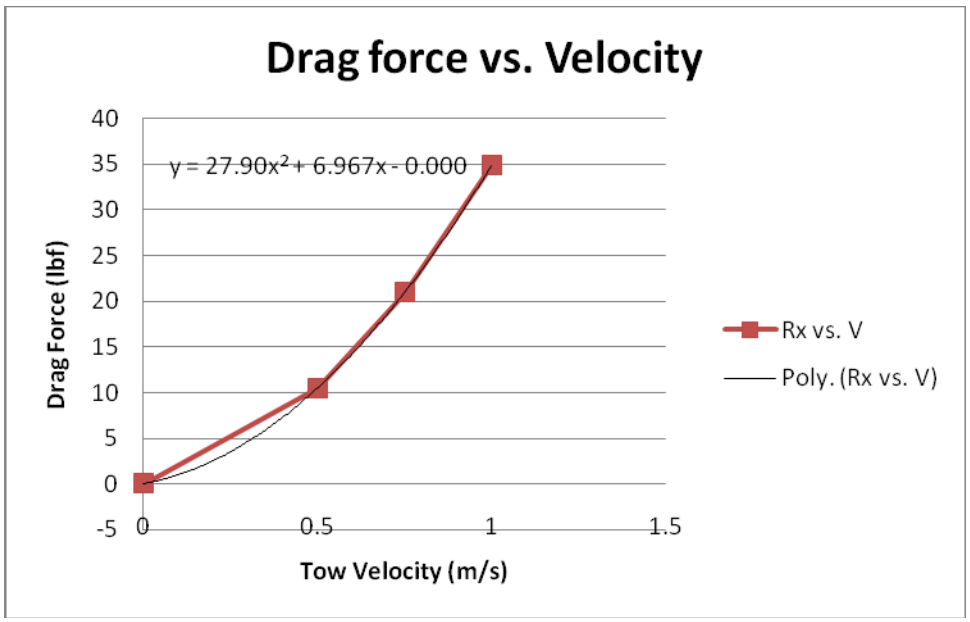


Figure 20. Drag force vs. tow velocity. Plot of Drag force vs. tow velocity for one lobster trap being towed in the UNH tow tank. The trend line represents the polynomial curve fit to the data, assuming that drag varies as V^{β}.

The culmination of this experiment and series of calculations were to develop a method for predicting the end line tension of a series of traps in tow. In comparing the results of this numerical/lab testing to the field study results, values for the loading are similar in magnitude, albeit not terribly accurate, but certainly representative. Table 13 shows the analytical data based upon the drag calculations and tow tank tests. The average of the loading data from the field tow test shown in Table14, are generally less than the analytical.

Table 13. Numerically derived drag values. Sample of numerically derived line drag forces with and without the measured drag of a trap from the tank tow test. These values were based upon a 2kt simulated towing speed, and all values are measured in pounds.

Depth	Shallow	Shallow	Medium	Medium	Deep	Deep
Scope	Short	Long	Short	Long	Short	Long
5(line only)	134.13	106.96	207.99	202.4	N/A	N/A
10(line only)	N/A	N/A	355.63	482.43	774.69	842
5(traps inc)	520.08	492.91	593.94	588.35	N/A	N/A
10(traps inc)	N/A	N/A	1127	1254	1546	1614

Table 14. Load averages for field tow tests. Load averages for the field tow tests broken down in the same fashion as the analytical prediction data in Table 11. Loads are in pounds.

Depth	**Shallow**	**Shallow**	**Medium**	**Medium**	**Deep**	**Deep**
Scope	**Short**	**Long**	**Short**	**Long**	**Short**	**Long**
5 traps	530.68	574.06	546.71	455.37	N/A	N/A
10 traps	N/A	N/A	556.62	603.56	580.81	567.92

The difference between the field data and the analytical data is much less for the five trap trawl then for the 10 trap trawl, for several possible reasons. One reason is that there was significantly less bottom influence on the five trap trawl field data because the traps were almost always off the bottom, whereas with the 10 trap trawl this was not always the case. The variability in the oncoming water velocity during a field tow (taking into account boat speed coupled with currents, etc) compared to the controlled lab tows and analysis also adds to the differences compared to the field results.

Perhaps the most interesting variable that was neglected in the analytical approach is that of lift in the traps as they are towed, which may alleviate some of the force imparted by the trap drag component. Lift in the towed trap was not measured in the tow tank tests, but would have, and most likely did occur during the field tow tests. Since the traps in the towed trawls were not rigidly connected to the ground line, they could pivot, making the trap at an angle, rather than completely normal to the incident flow. This would make the trap act much like an airfoil, creating a lift component, making the trap travel up in the water column, and alleviating some of the end line tension. Since the analytical model did not account for this lift term, 10 trap trawls have a much more significant end line load than does a five trap trawl. However, in the field experiment, although the 10 trap trawls experienced a higher load than the five trap trawl, the difference was not as significant, meaning that another force (lift) was potentially alleviating

some of the end line tension that would not normally occur in a purely drag scenario.

CONCLUSIONS

The goal of the comments here is to look at the overall results presented above and attempt to clarify and further define and refine the TTLC. All the comments are made with the knowledge that the data are limited, but do show promise for the TTLC as a useful device.

The field tow tests were a success. There were many trials and in each case the TTLC behaved as anticipated. The load measurements were revealing as the magnitude of the loads for all 5-10 trap trawls were below 1100 pounds. The results from the pressure measurements used to define the trawl profile when the test was at a steady state. The 10 and 20 trap trawls were a different situation. Some of the traps remained on the bottom even during the steady state part of the test. The steady state was reached when the *Jesse B* came up to speed and the load effectively remained constant before the TTLC made the line cut.

The pilot study intensity was less than desired, yet there are still useful results. The TTLC were initially tested for the TTC value with a new blade in the TTLC. They were then fished for ten hauls and returned for retesting the TTC. The majority of the retest yielded TTC values which were higher than the original values. One fisher was able to redeploy the TTLC for a second round of use and they were subsequently tested again for TTC. Another fisher left the gear on the bottom over the winter of 2008-2009 and hauled it in the Spring 2009. There were 19 TTLC returned in the late Fall 2009 which were subsequently tested for TTC in an attempt to understand the increase in the TTC from the original, unused testing. Five TTLC were selected randomly from this group of 19 and new blades were installed and they were tested yet again. These results indicated that the TTLC internal hydraulic workings were performing as expected and that the used blades were the culprit causing the increase in TTC. Many of the used blades had nicks or rolled edges which slowed the cutting process, but they all did ultimately cut the line.

The analytical model proved to be an interesting addition to the field tow testing as it verified some numbers (particularly with the 5 trap trawl data), and

most importantly, identified the contributing forces acting on the end line in an entanglement. A more robust model would allow for an accurate prediction of end line tension.

All experimental testing and gear evaluation in the ocean can be considered differently after the experiments are completed. This is part of the process. In this context some evaluation of this work is presented. In terms of the field tow test, improvements in the testing protocol regarding an accurate measurement of the trawl tow speed would make the data more consistent in terms of controlling the speed variable. More work on 20 trap trawls would refine the understanding of the loads involved in entangled gear. Also, using an attitude sensor to measure the angle at which a trap lies naturally while being towed on a trawl could prove to be useful, especially in terms of tailoring a future controlled tank test to determine the lift contribution of a towed trap.

The analytical approach to modeling the trap movement, using a numerical model and a tow tank test also has some room for improvement. The inclusion of a lift measurement in the tow test could prove to be valuable and may yield results closer to that of a field tow test. This would be accomplished by holding the trap at a variety of angles and using a load cells that could be rigged in a way to measure lift as well as drag. This coupled with the data from an attitude sensor in a trap during a field tow test, and correlating the natural tow angle with the lift force generated using a tank tow at that same angle would enhance the development of a more representative analytical approach.

Continuing the pilot study to evaluate the robustness of the TTLC and the comfort level of the fisherman using the device over a long time frame would be beneficial. The pilot study was useful as the feedback obtained from fisherman on how the TTLC would handle once they were deployed in a real fishing situation. It was also be valuable to test used TTLC for their repeatability after being used for a longer time. The units all functioned when they were returned after being fished, with most of them having a longer TTC than they did before they were deployed. This is likely due to blade integrity as a result of multiple

cuts with the same blade. This also is consistent with the findings of Baldwin and Landino (2007).

The field, tow testing and pilot study were completed in an effort to test the TTLC as a whale safe fishing alternative. An analytical model was developed to investigate and verify the results of the field testing portion of the project. The data collected in the field testing were useful in determining the behavior of lobster trawls in tow, as they could be in an entanglement scenario. The trap profiles showed a dependence on water depth, end line scope, and the number of traps in the trawl. Nevertheless, the TTLC preformed as designed for any type of configuration, under the common loading scenarios, and anomalies in the cut times were commonly attributed to the blade in the unit deteriorating over a series of cuts.

REFERENCES

Risso, A.M. (2007). *Structural Analysis of a Small Volume Offshore Aquaculture Cage System Using Numerical Modeling and Scaled Physical Testing.* Master's Degree Thesis submitted in partial requirement for the Degree of Master in Ocean Engineering. University of New Hampshire, Durham, NH. 276p.

Baldwin, K. and Landino, D. (2007) *"Report covering funding period from Aug 2006-Mar 2007"* report prepared for the New England Aquarium.

Fridman, A.L. (1986). Calculations for fishing gear design. Fishing News Books, U.K. 241p.

APPENDICIES

APPENDIX A: Trap movement daily composite and average results

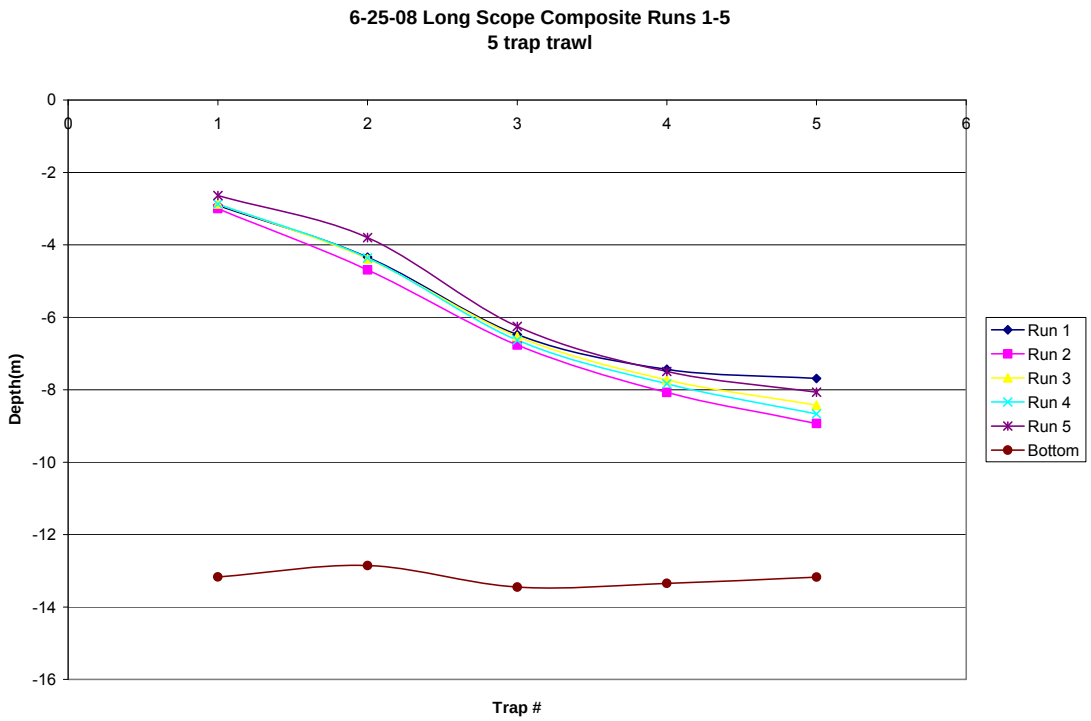


Figure A.1 Composite plot of 5 runs using a long-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

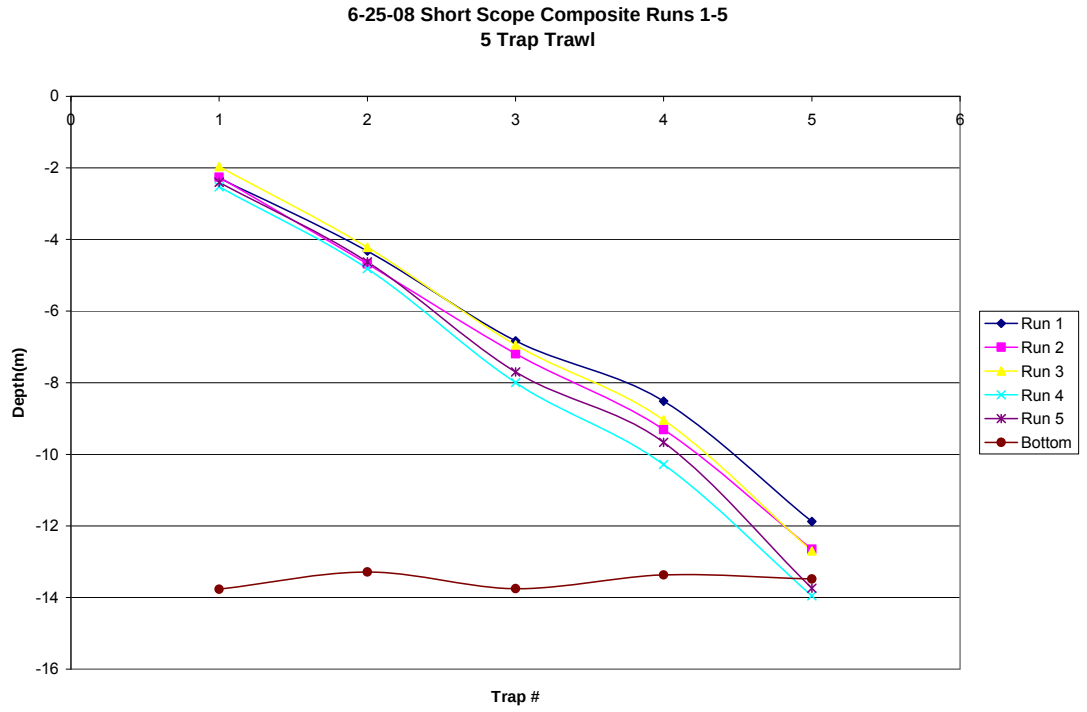


Figure A.2. Composite plot of 5 runs using a short-scoped endline as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

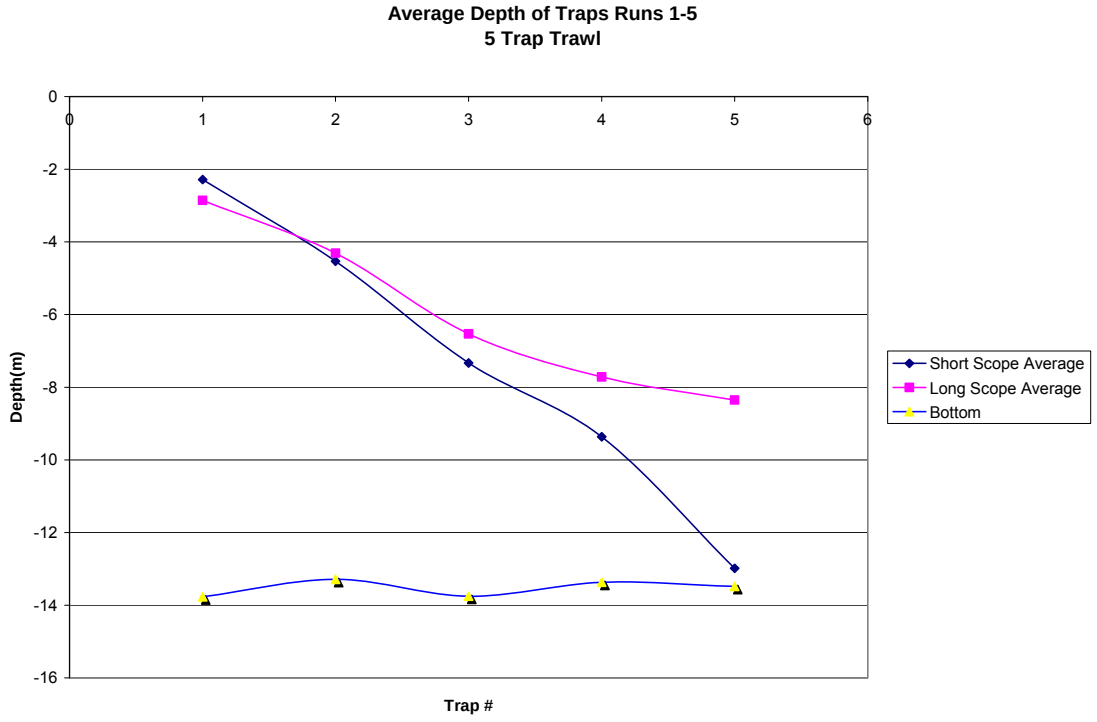


Figure A.3. Plot of the average of the long, and short-scope runs for a 5 trap trawl of the 6-25-08 day of testing.

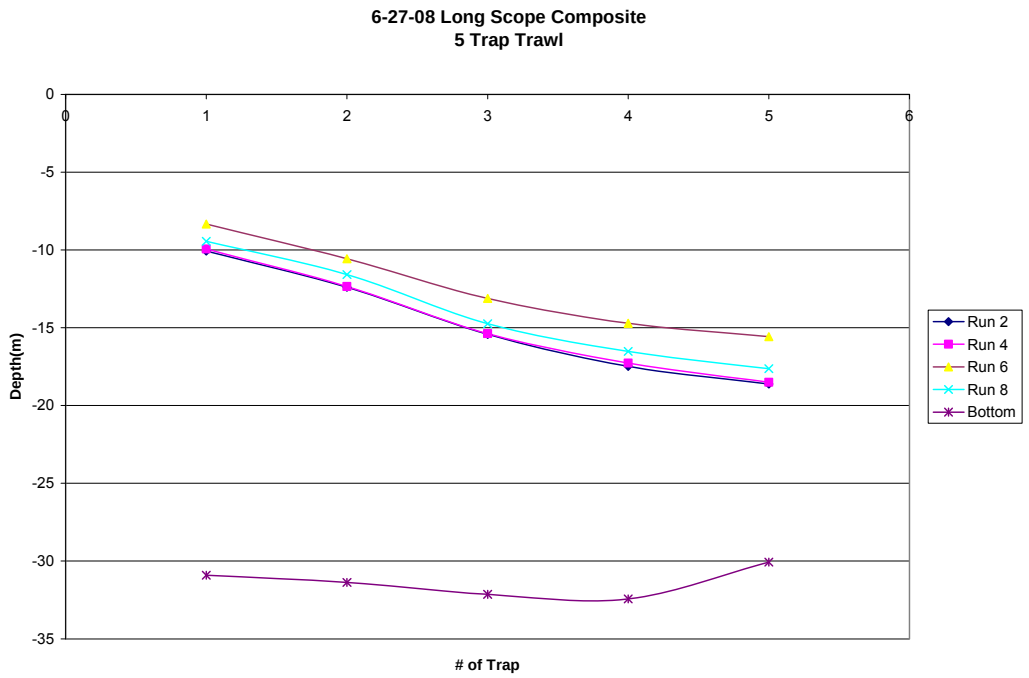


Figure A.4. Composite plot of 5 runs using a long-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

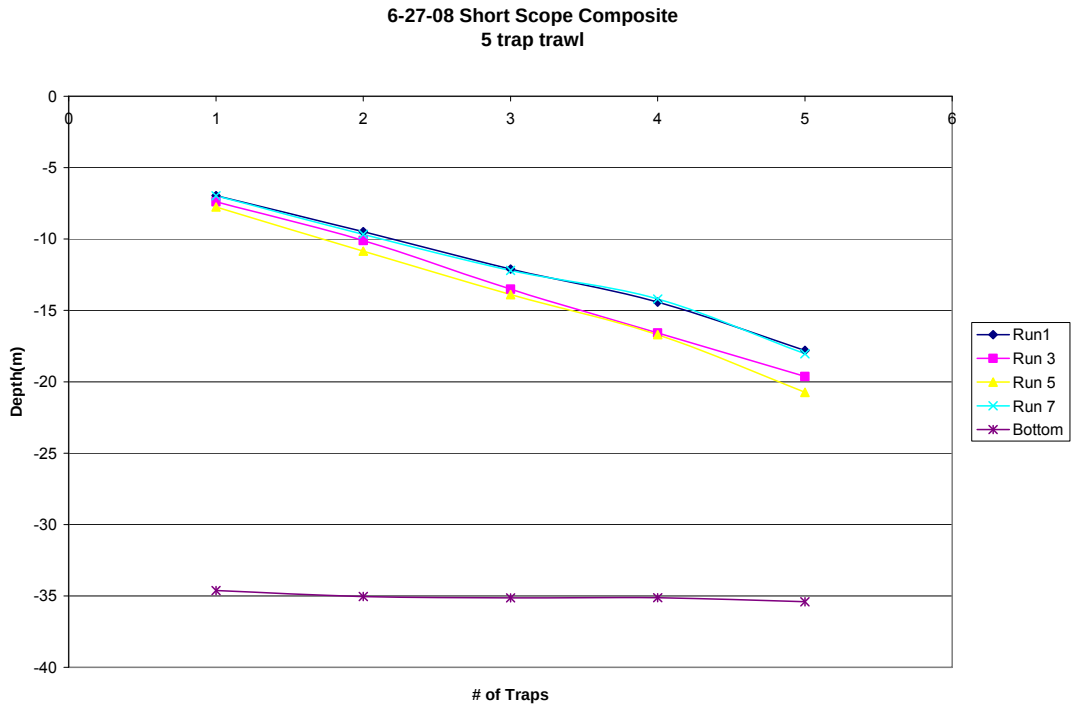


Figure A.5. Composite plot of 5 runs using a short-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

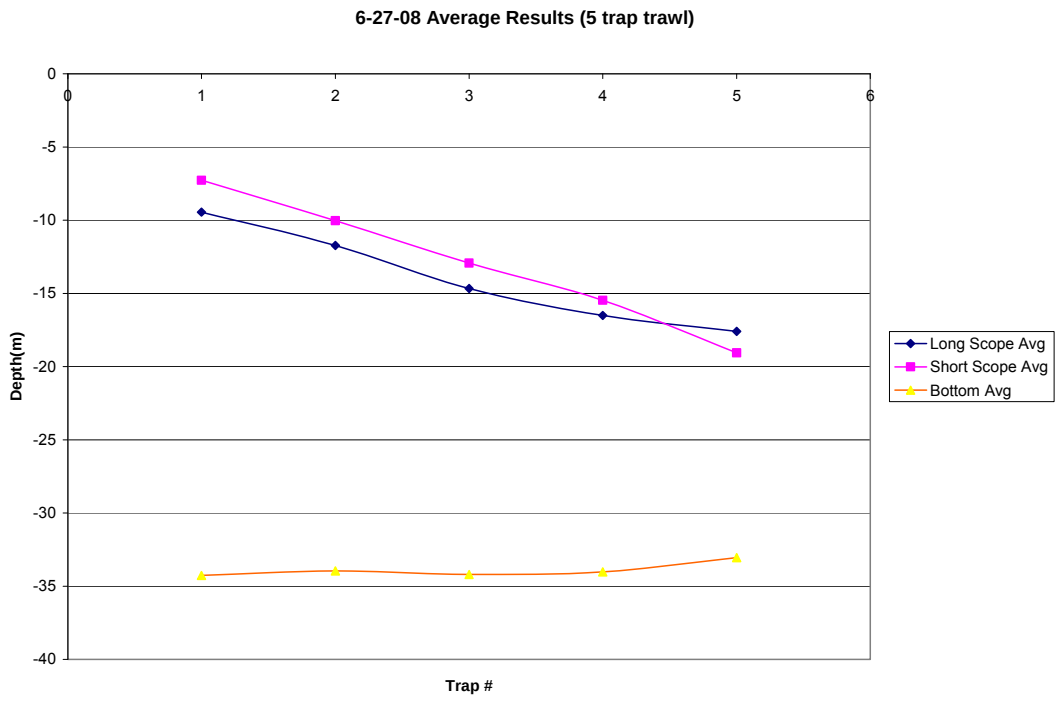


Figure A.6. Plot of the average of the long, and short-scope runs for a 5 trap trawl of the 6-25-08 day of testing.

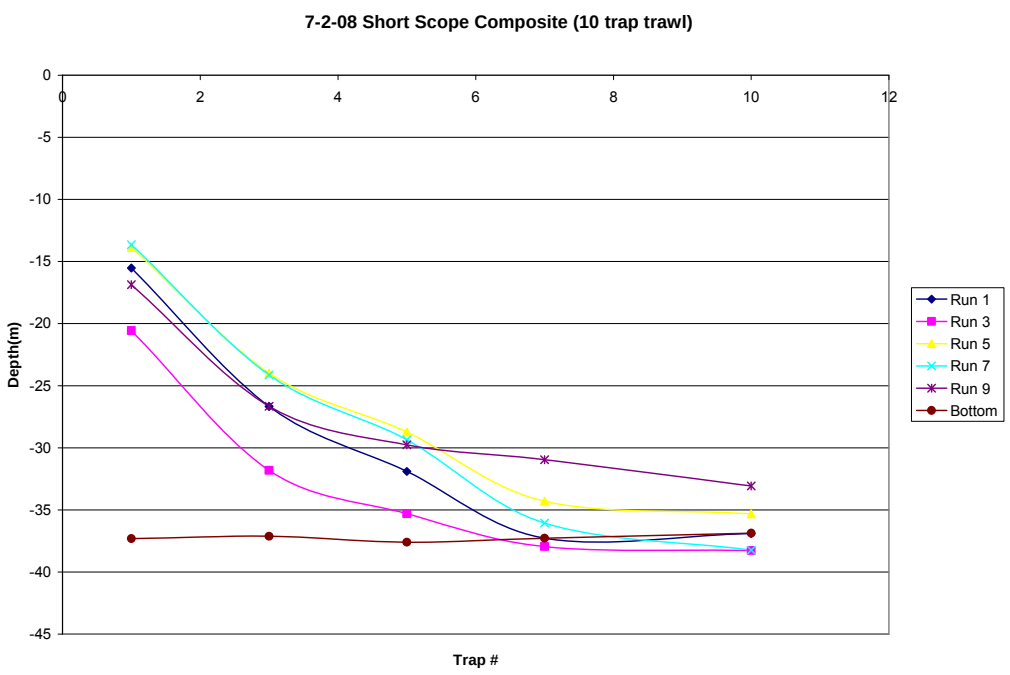


Figure A.6 Composite plot of 5 runs using a short-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

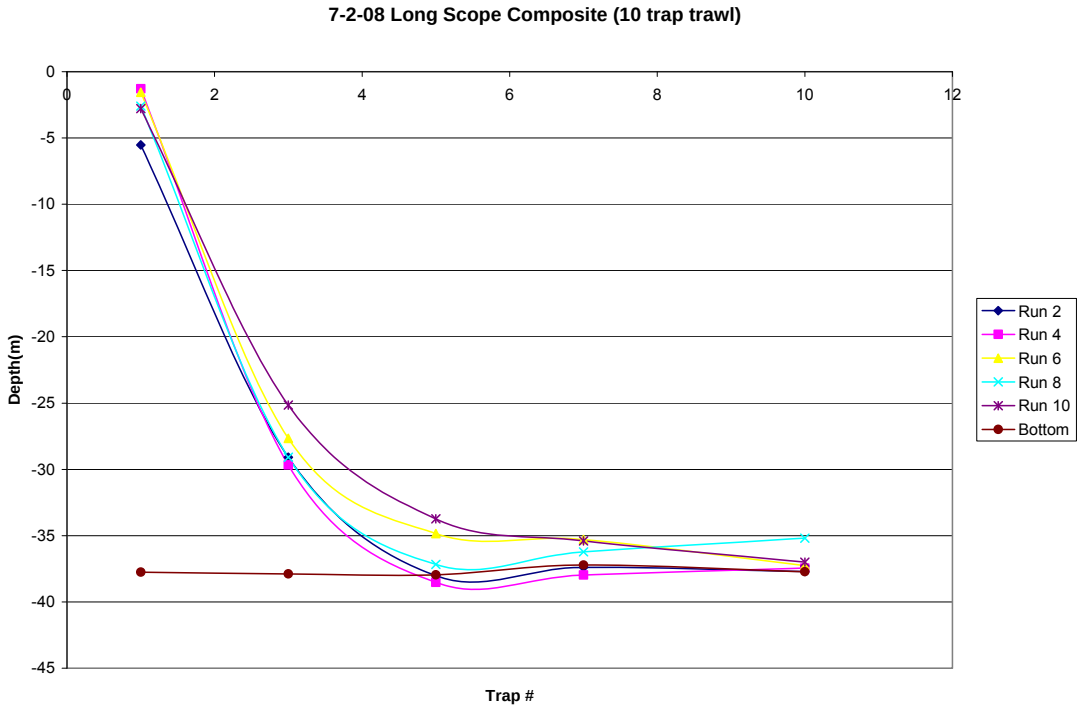


Figure A.7. Composite plot of 5 runs using a long-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

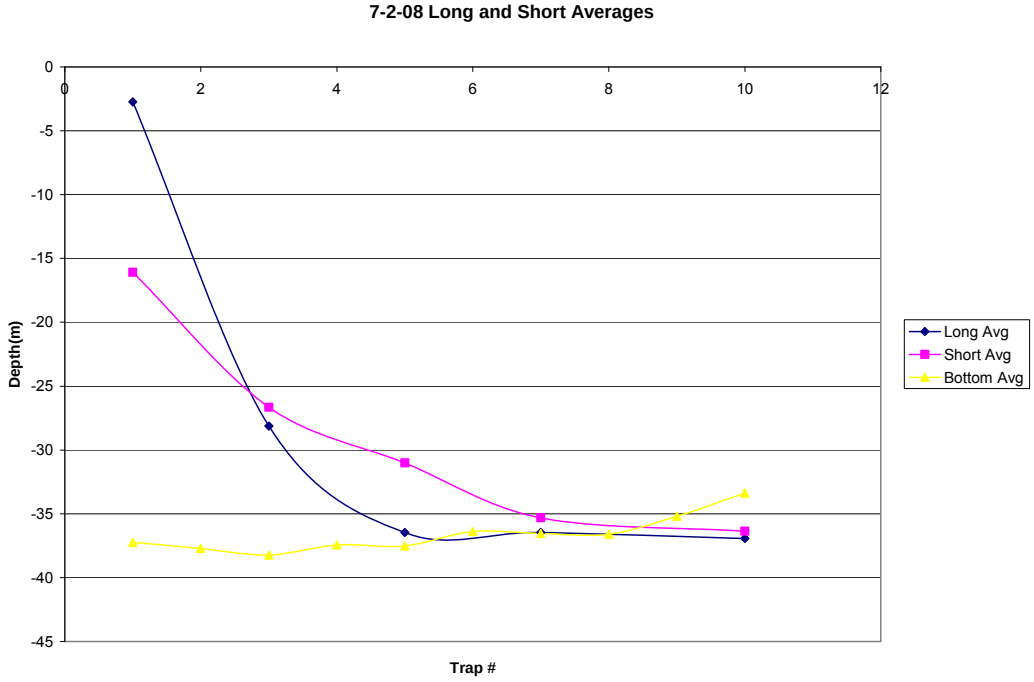


Figure A.8. Plot of the average of the long, and short-scope runs for a 10 trap trawl of the 7-2-08 day of testing.

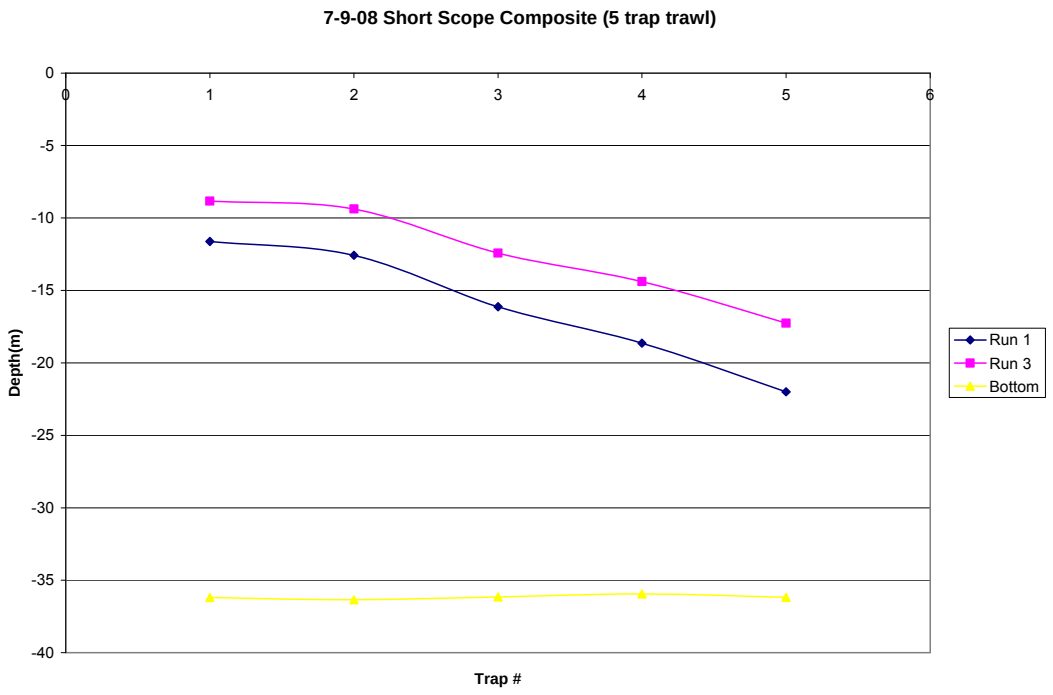


Figure A.9. Composite plot of 2 runs using a short-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

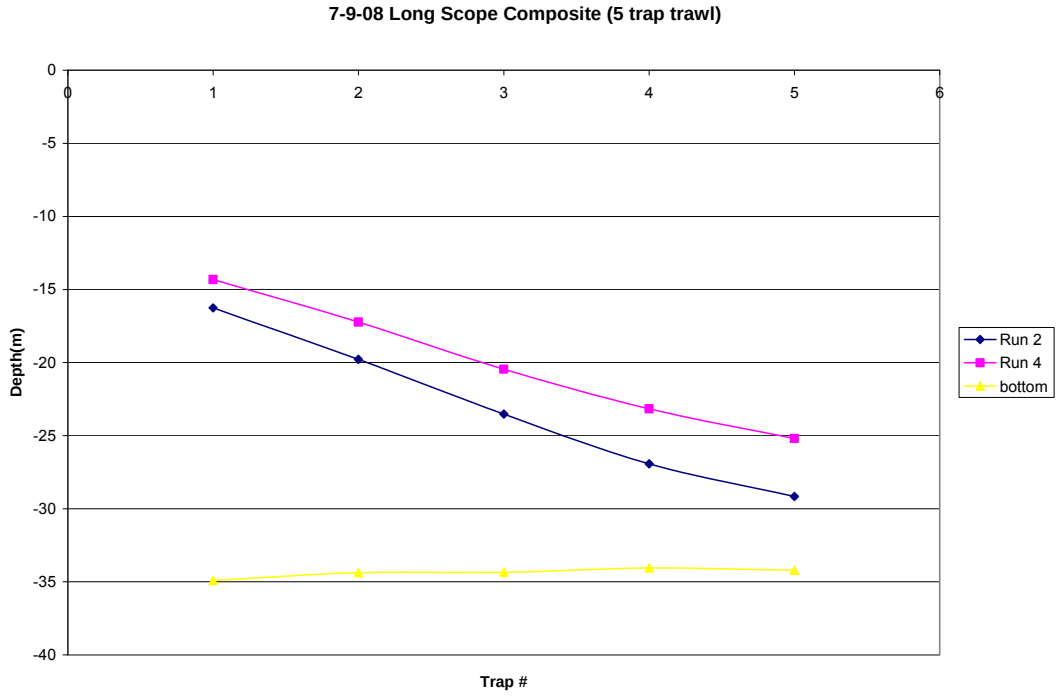


Figure A.10. Composite plot of 2 runs using a long-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

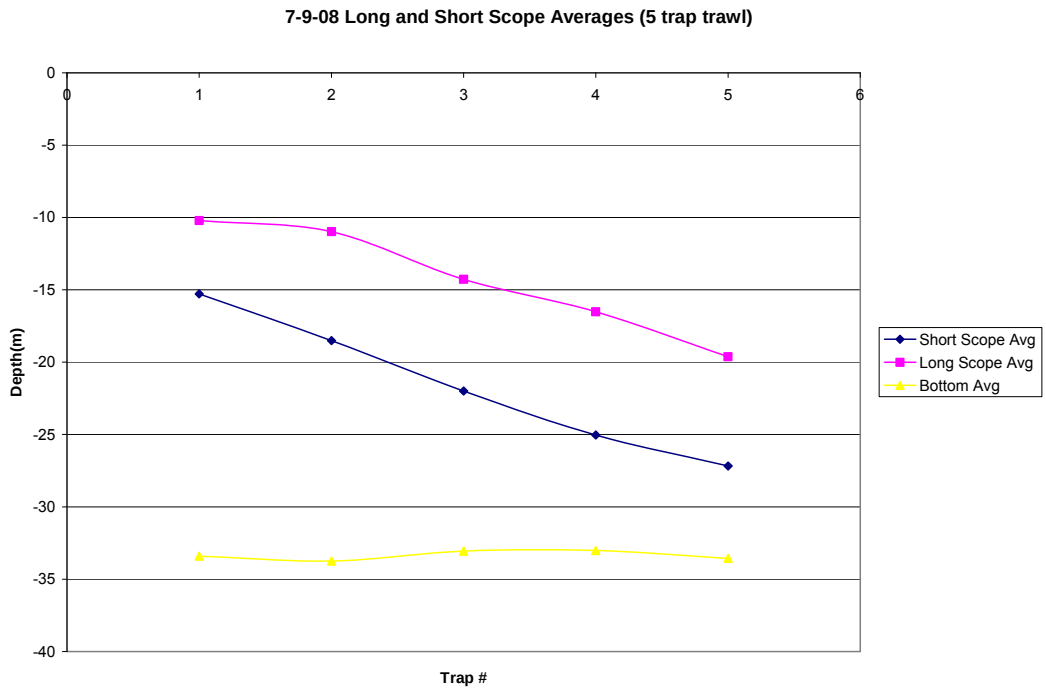


Figure A.11. Plot of the average of the long, and short-scope runs for a 5 trap trawl of the 7-9-08 day of testing.

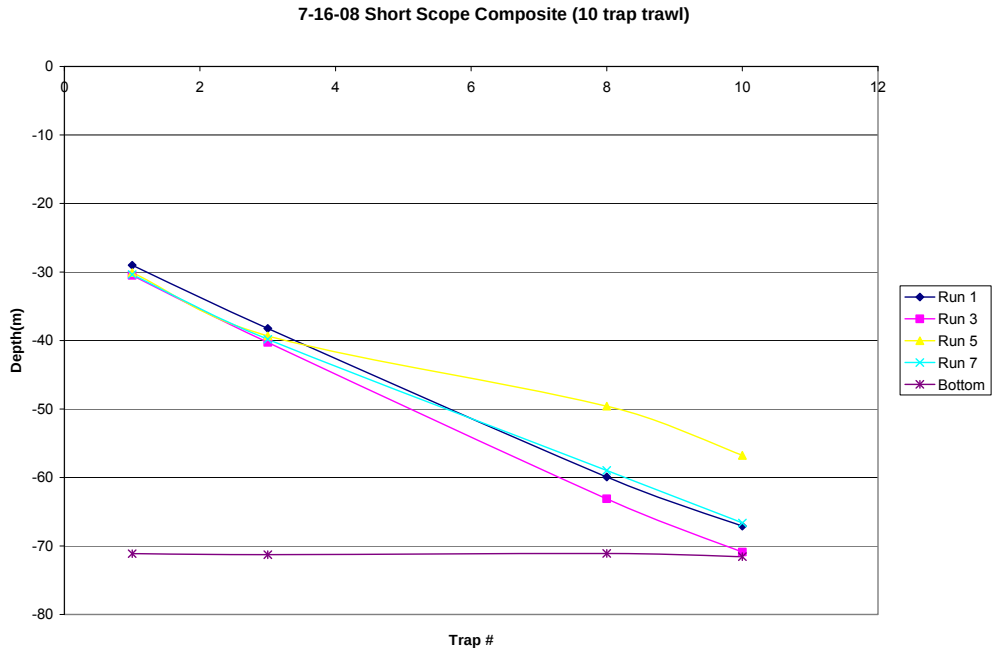


Figure A.12. Composite plot of 4 runs using a short-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

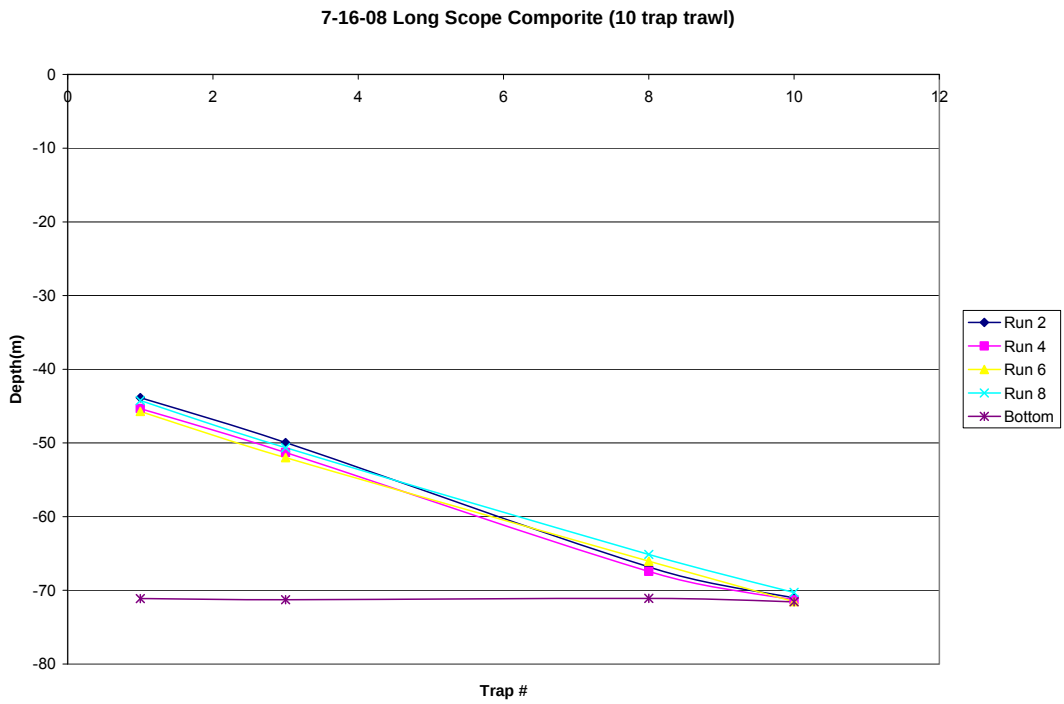


Figure A.13. Composite plot of 4 runs using a long-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

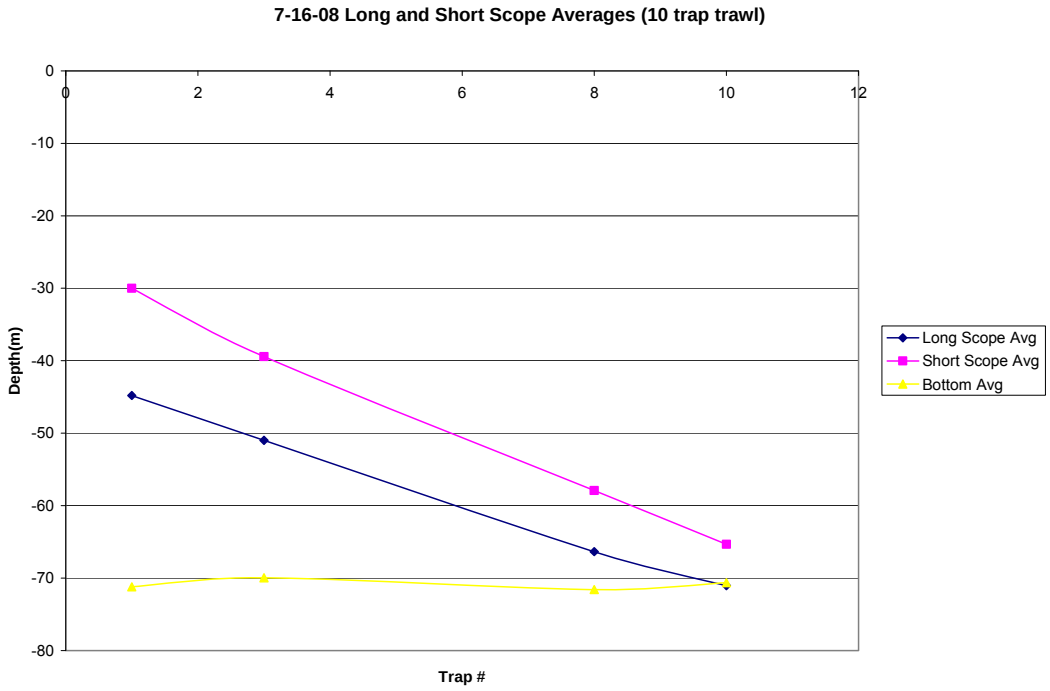


Figure A.14. Plot of the average of the long, and short-scope runs for a 10 trap trawl of the 7-16-08 day of testing.

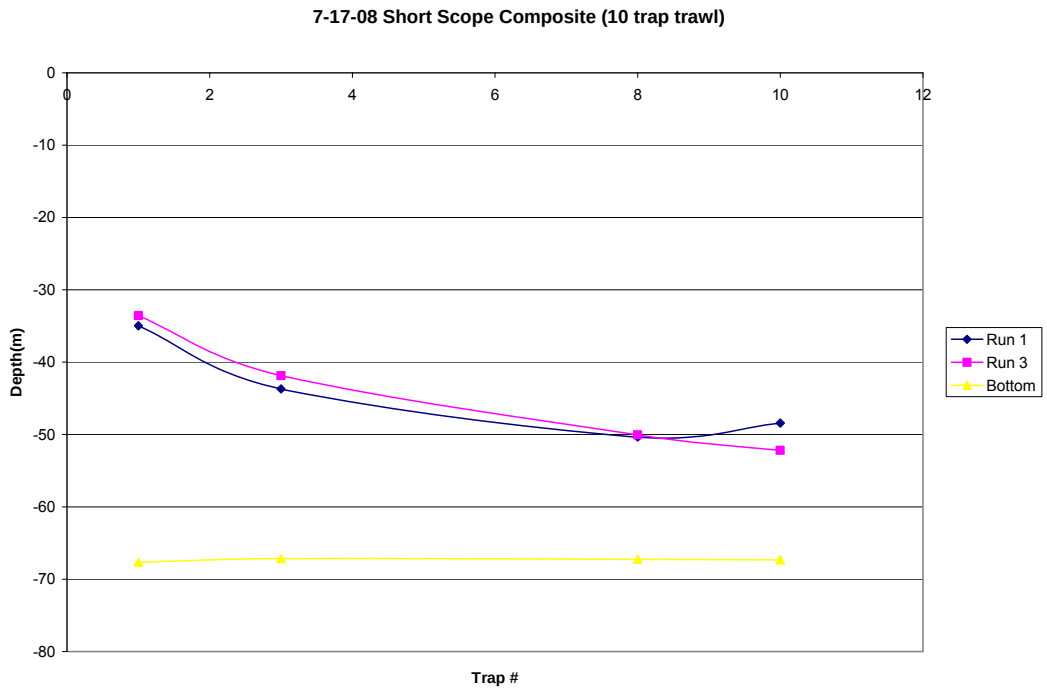


Figure A.15. Composite plot of 2 runs using a short-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

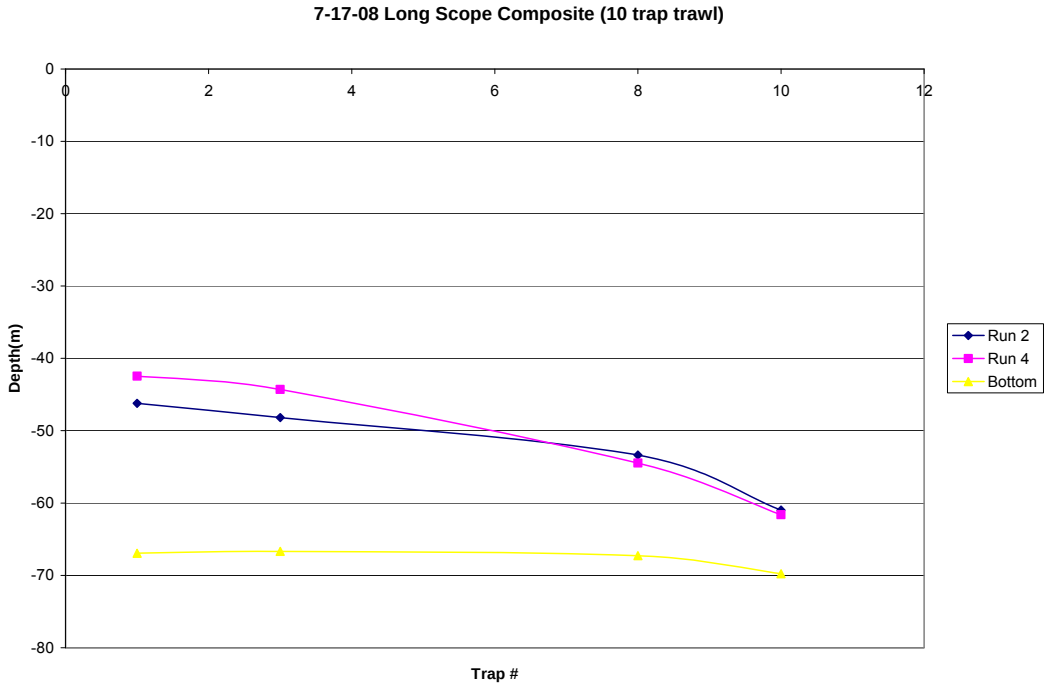


Figure A.16. Composite plot of 2 runs using a long-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

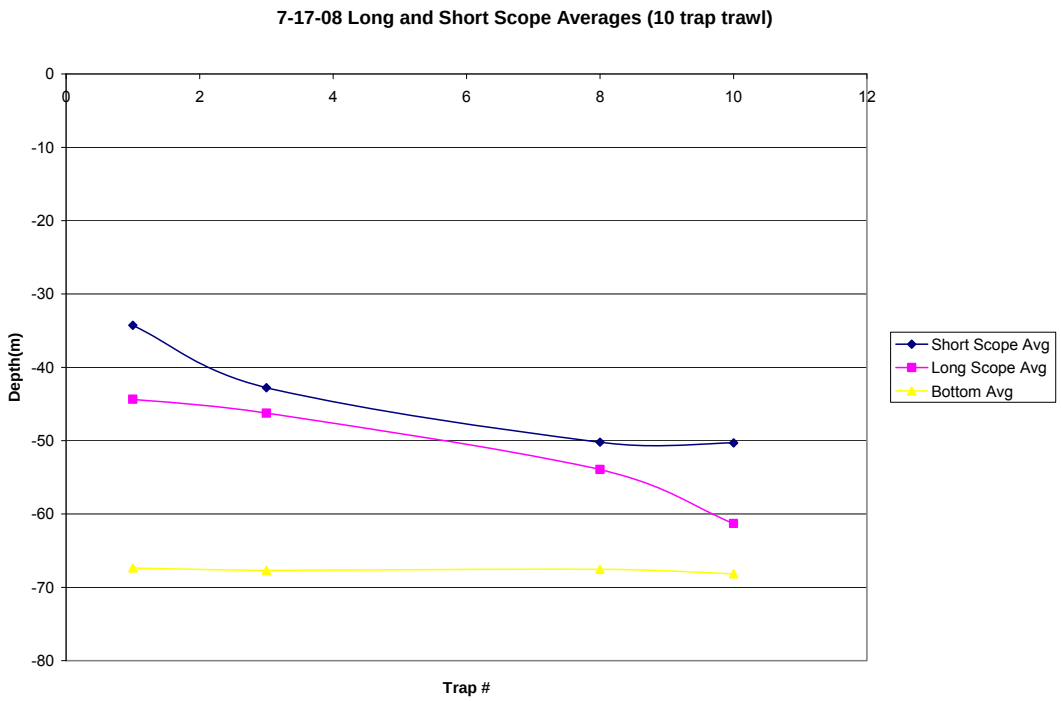
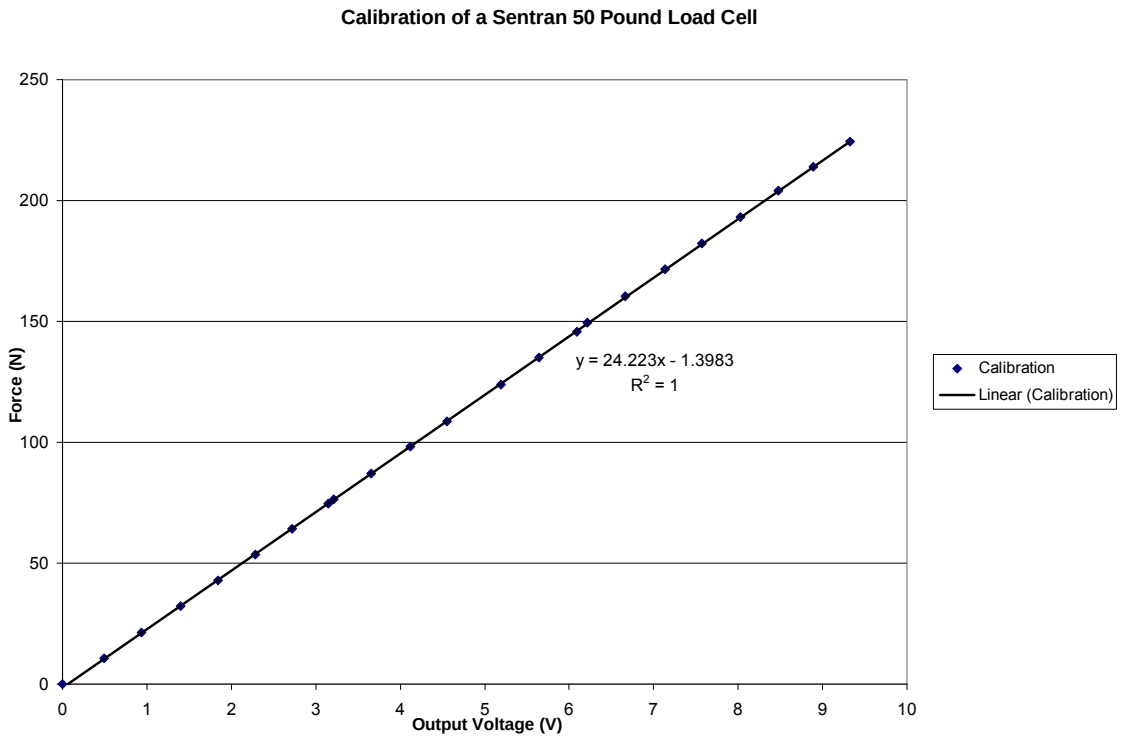


Figure A.17. Plot of the average of the long, and short-scope runs for a 10 trap trawl of the 7-17-08 day of testing.

APPENDIX B- Tow Carriage Load Cell Calibration Curve

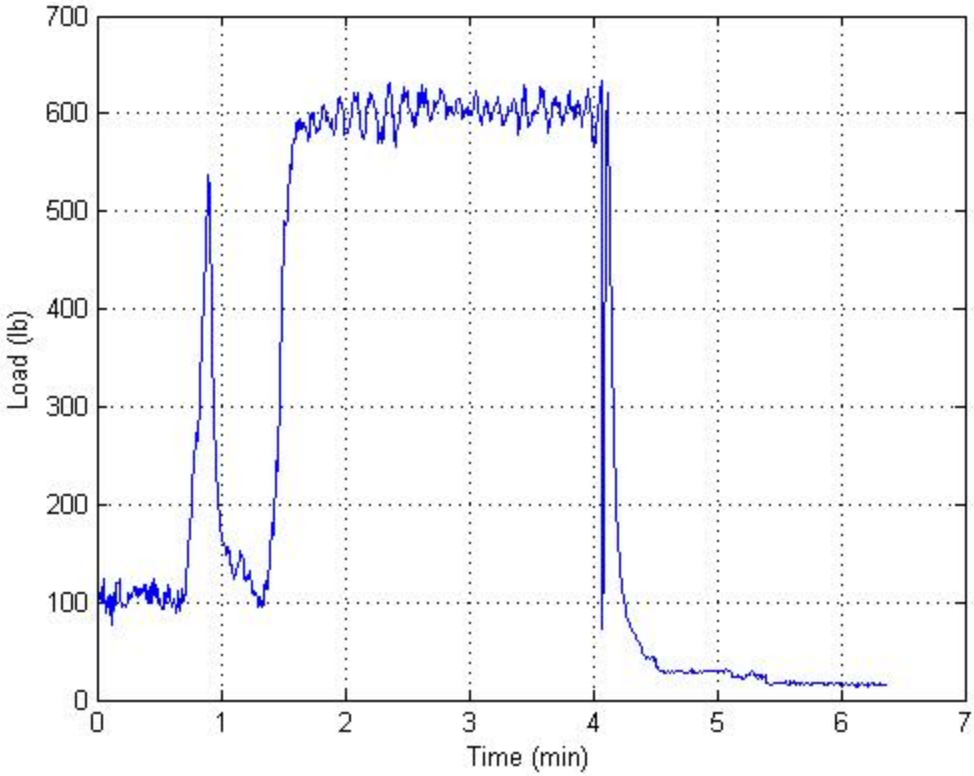


Appendix C

Load vs Time for all tow tests

06 25 08

A001-A010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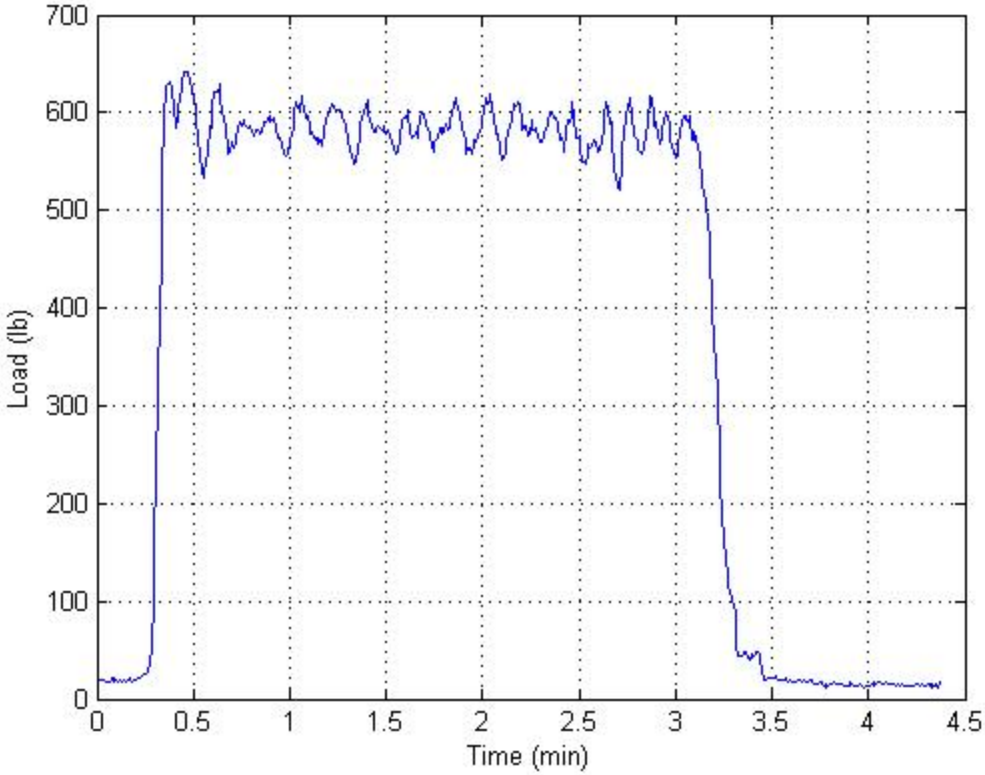
Time (min)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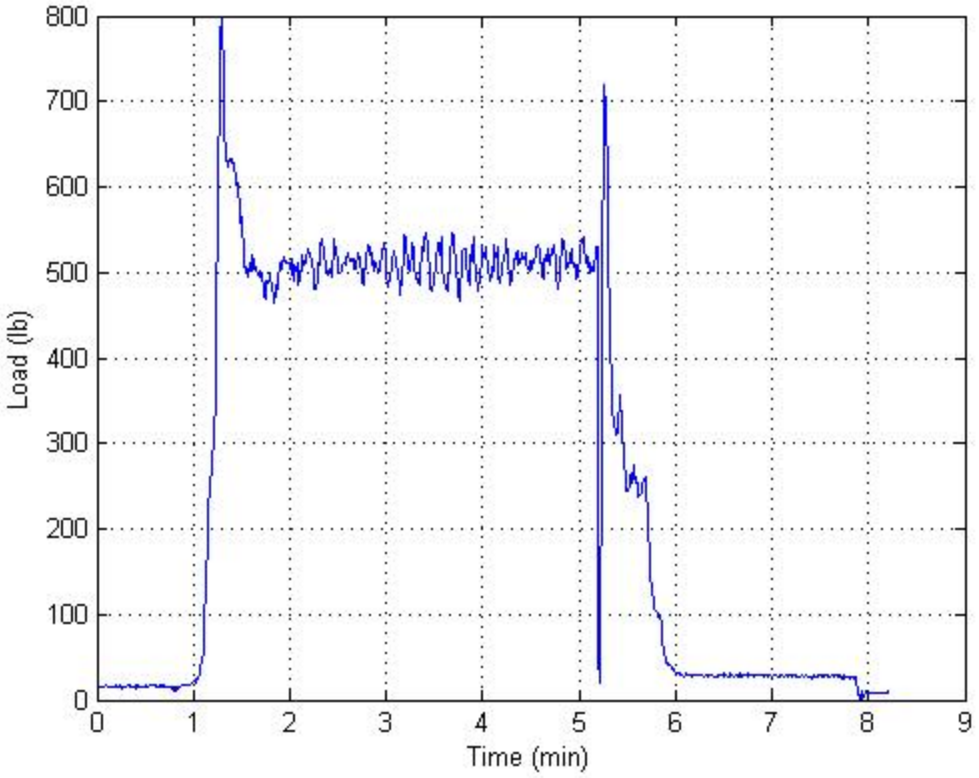
Time (min)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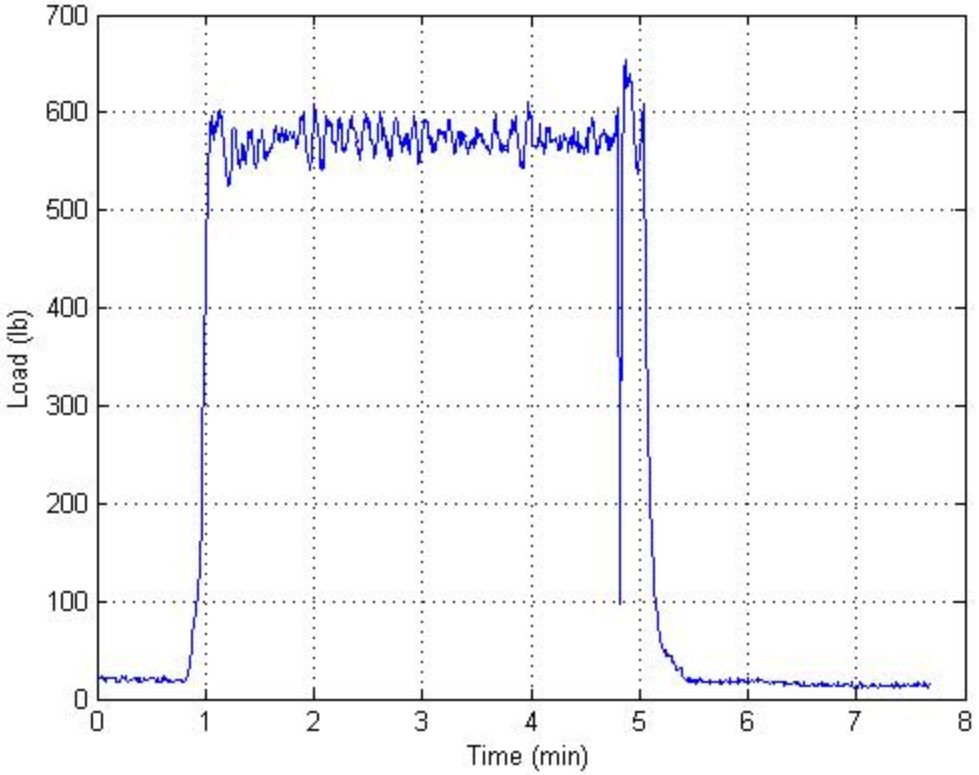
Time (min)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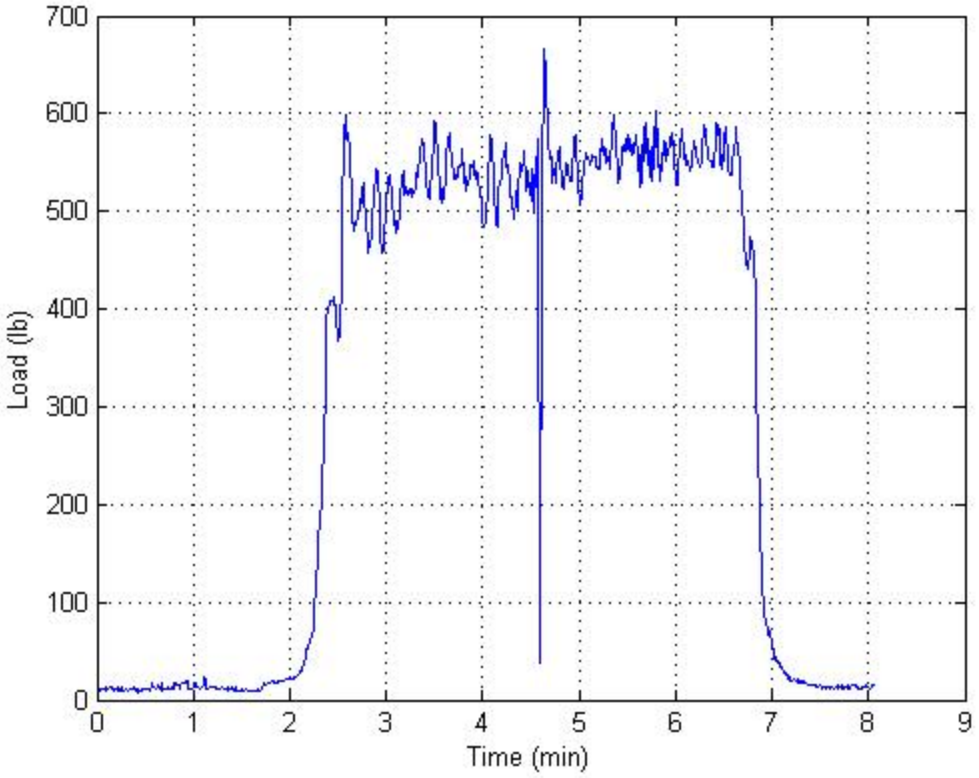
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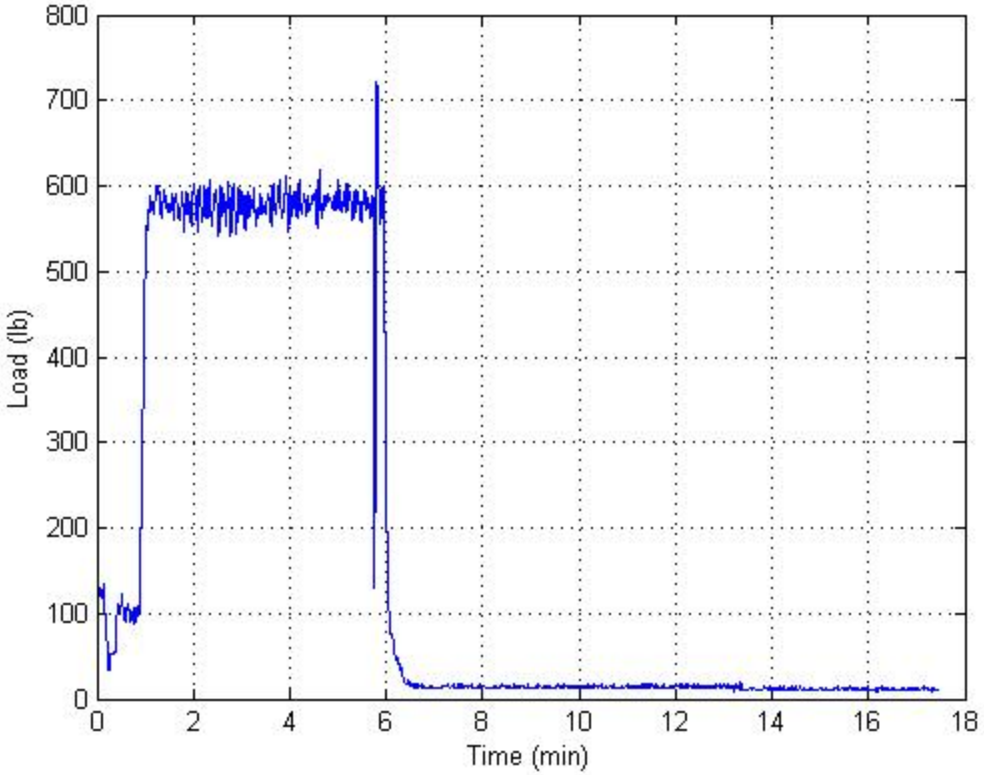
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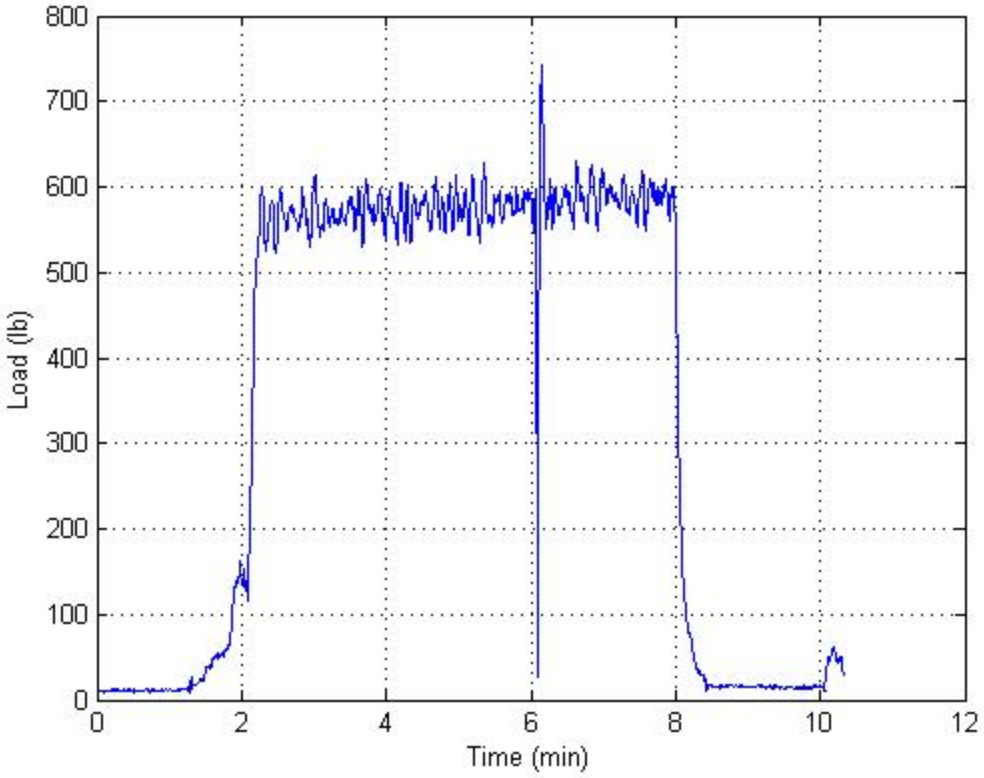
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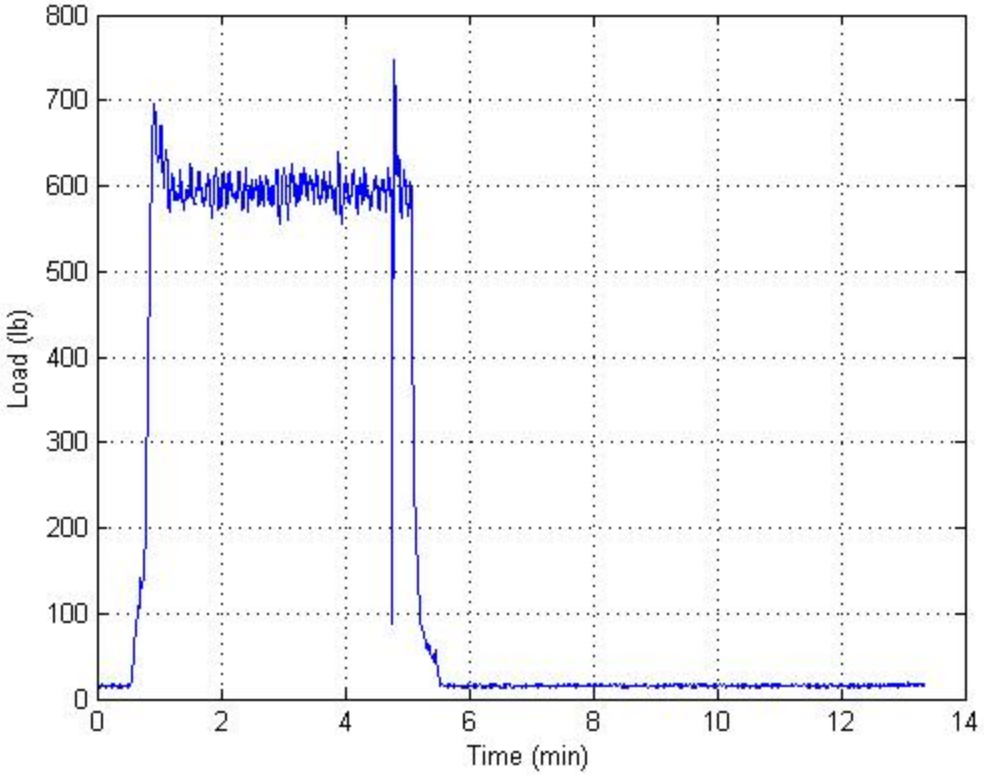
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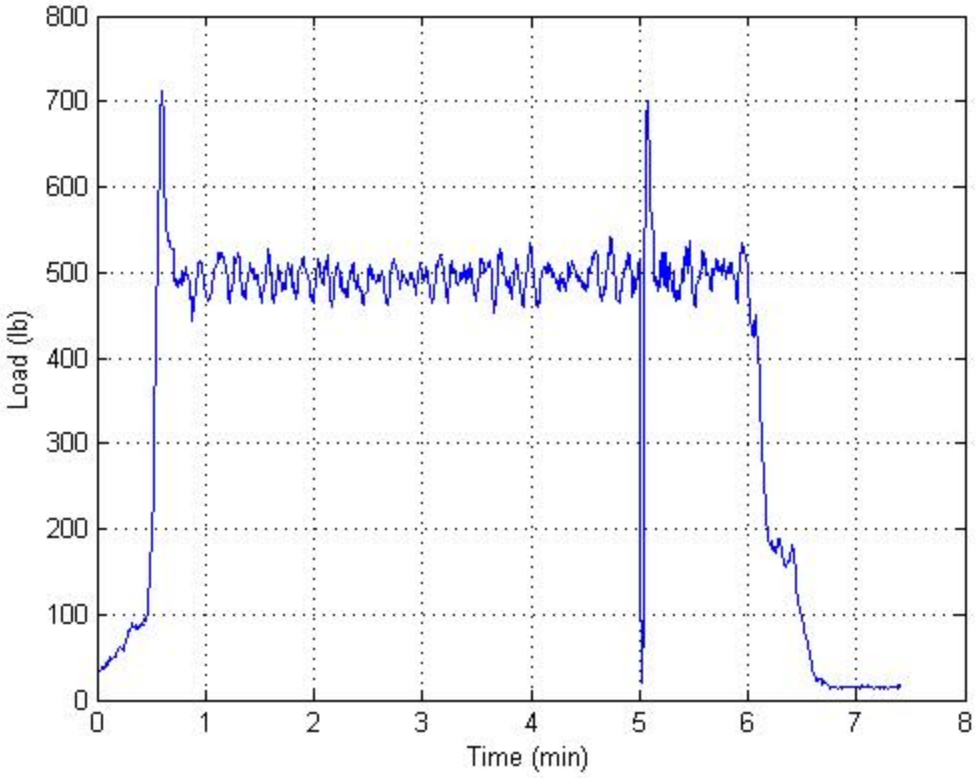
Time (min)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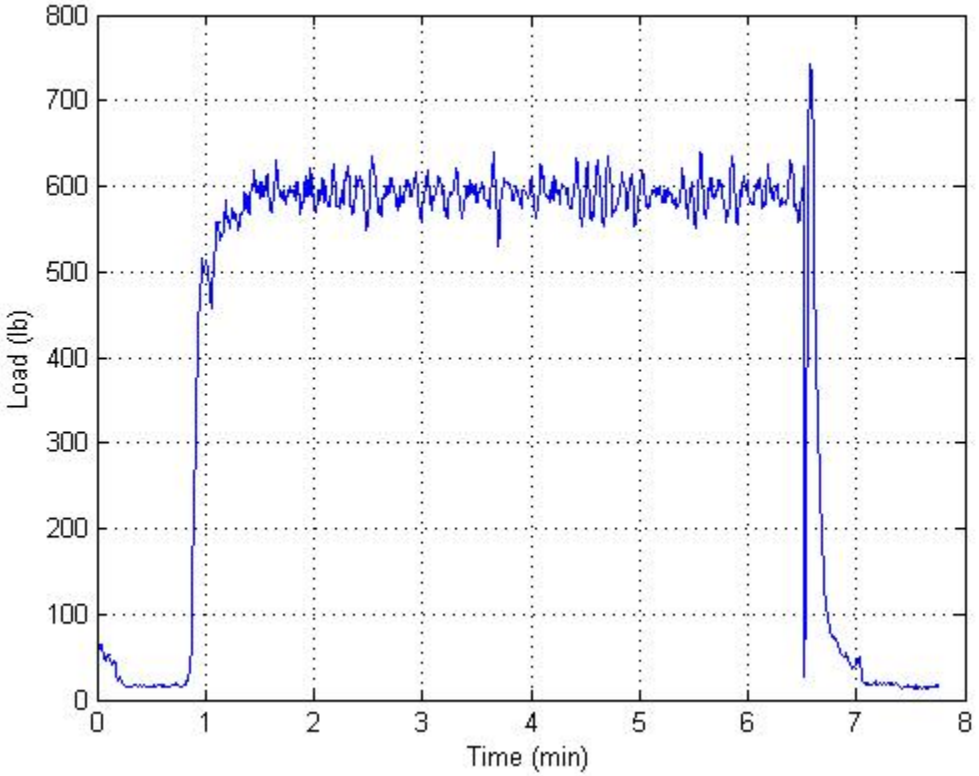
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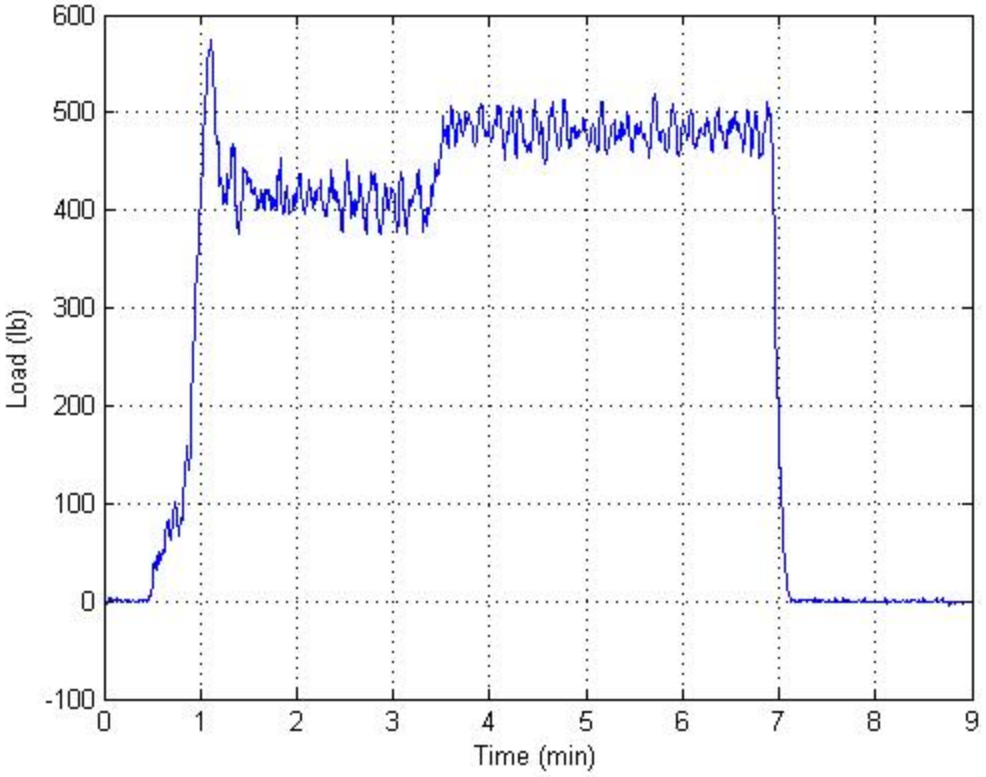
8
Time (min)

Load vs Time for all tow tests

06 27 07

A001 – A008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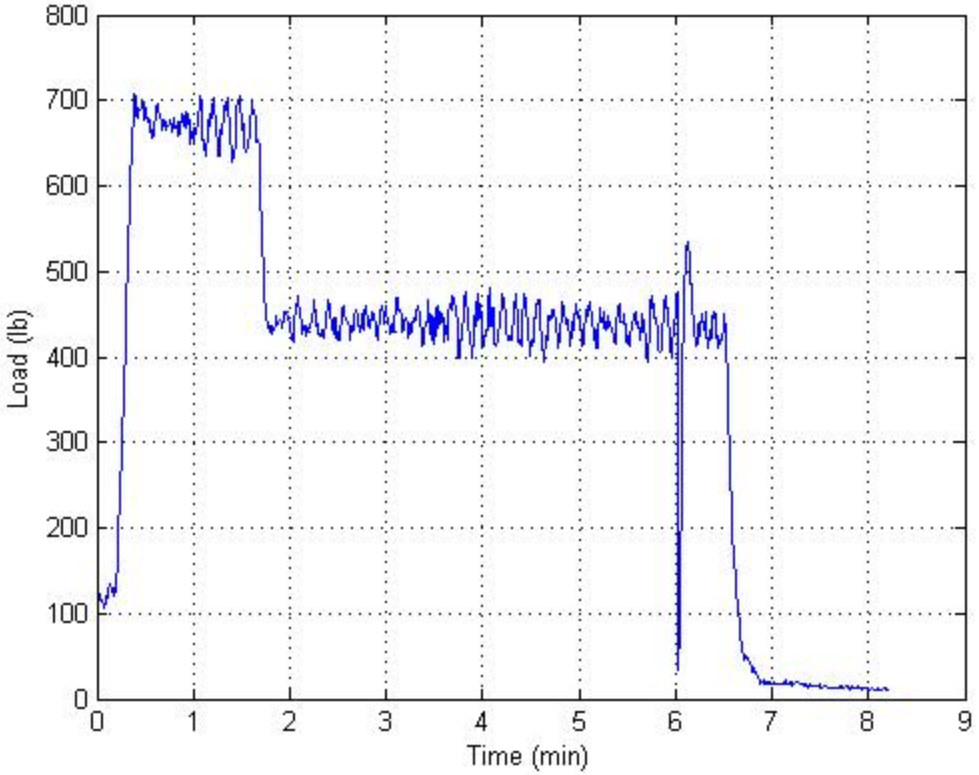
Time (min)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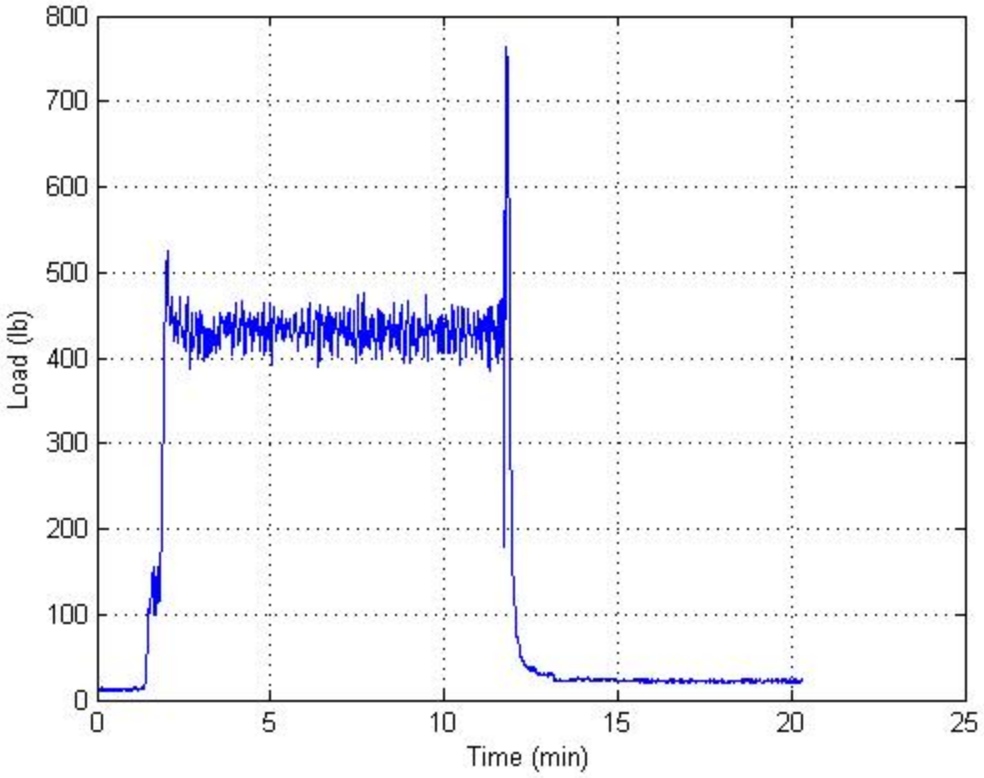
Time (min)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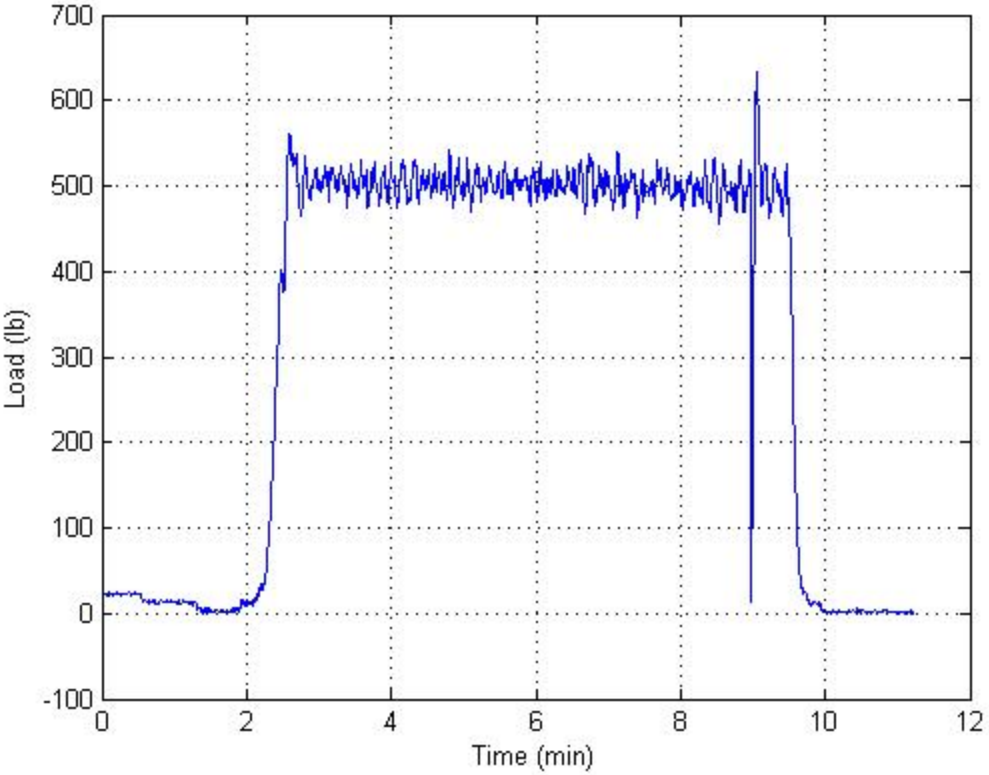
Time (min)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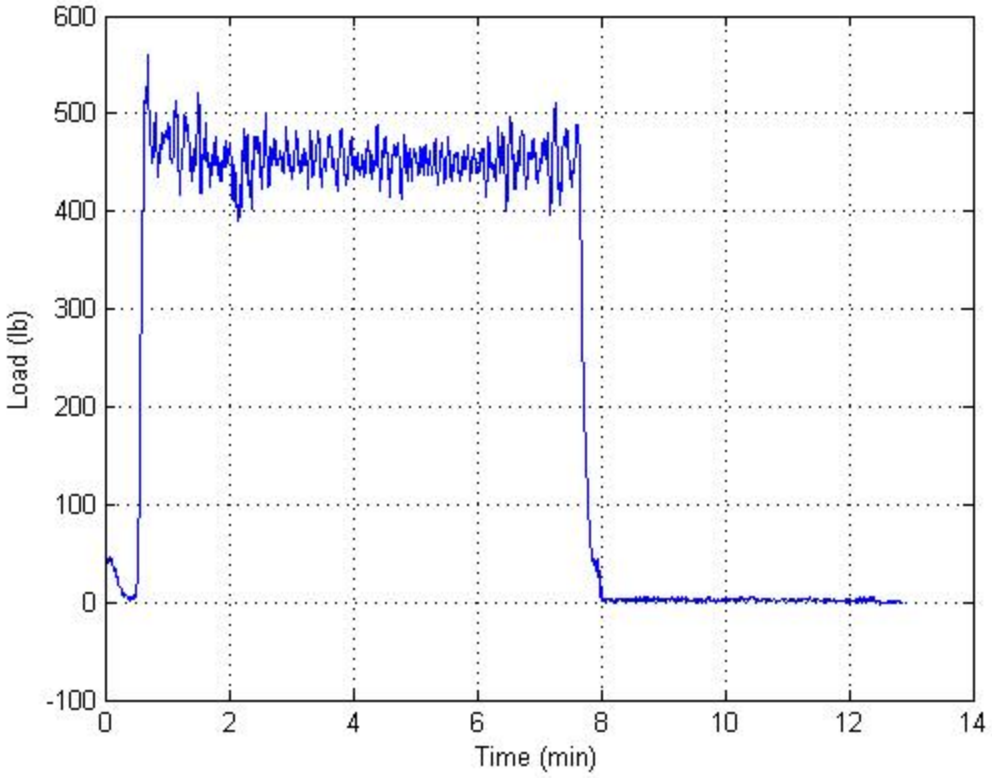
Time (min)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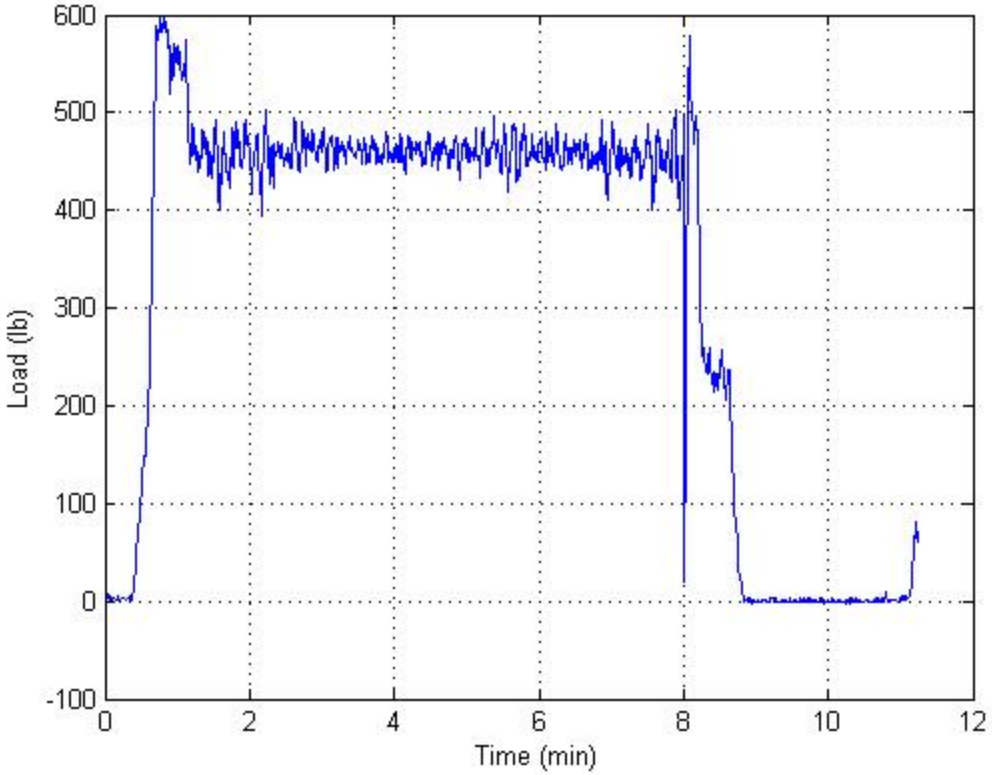
Time (min)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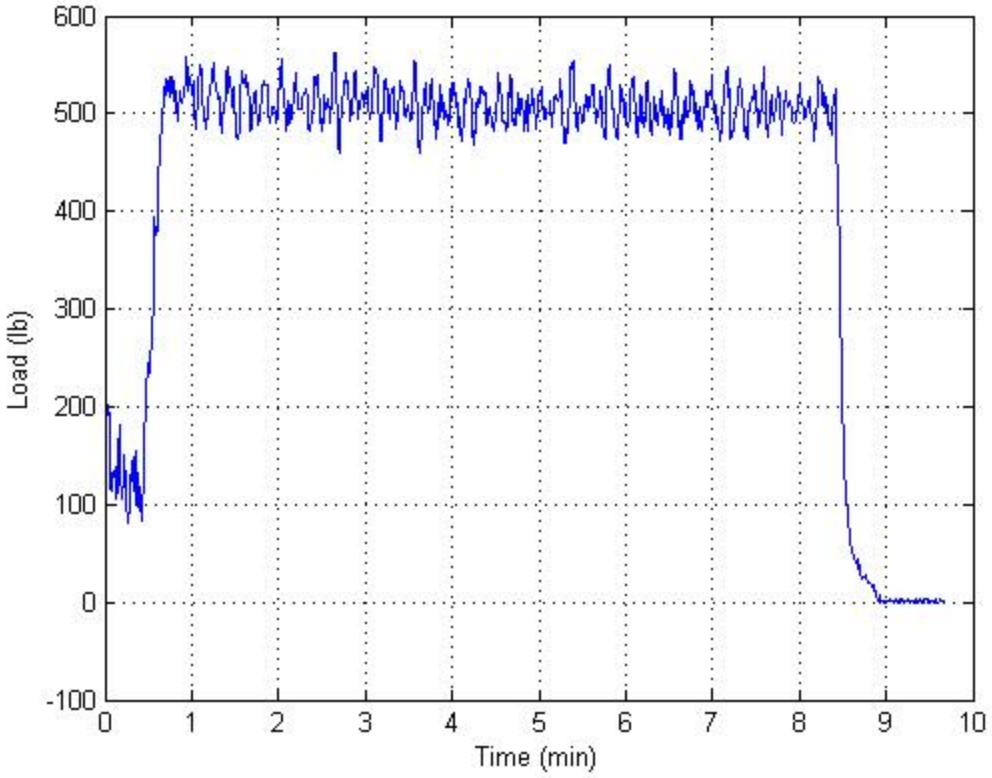
Time (min)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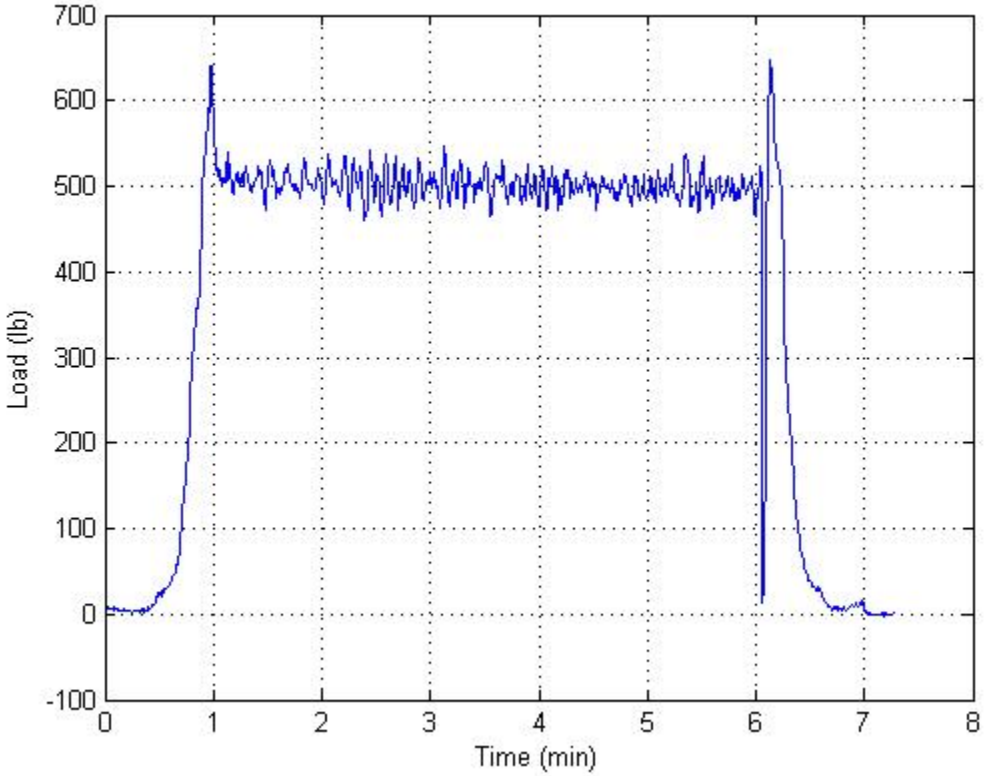
Time (min)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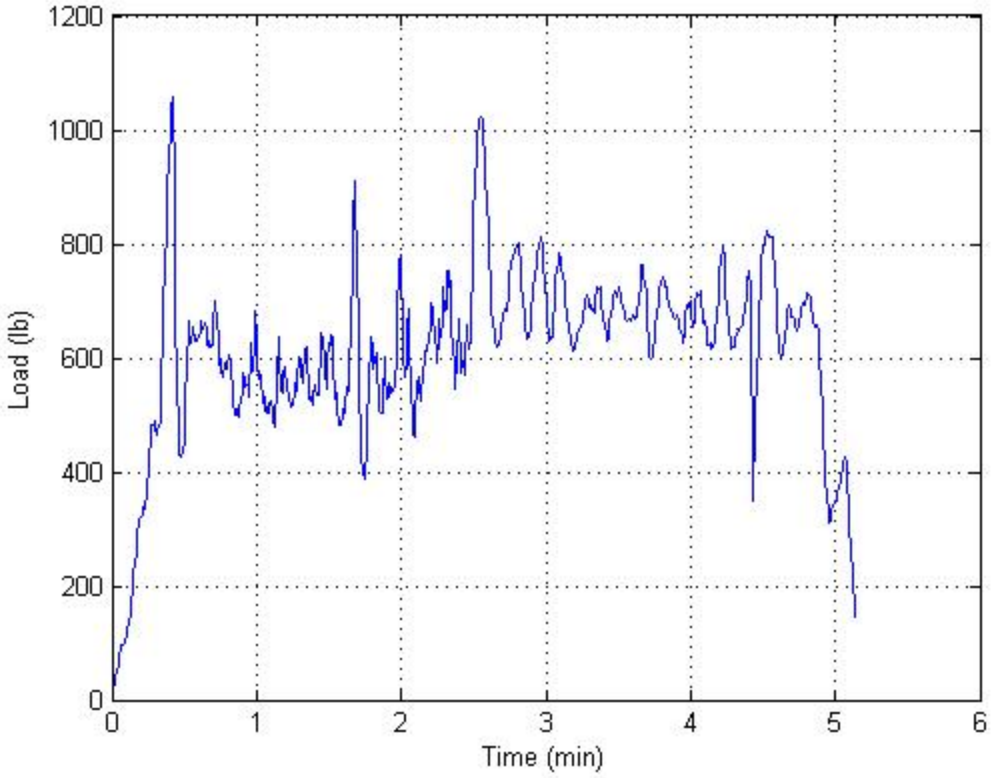
8
Time (min)

Load vs Time for all tow tests

07 02 08

A001 – A010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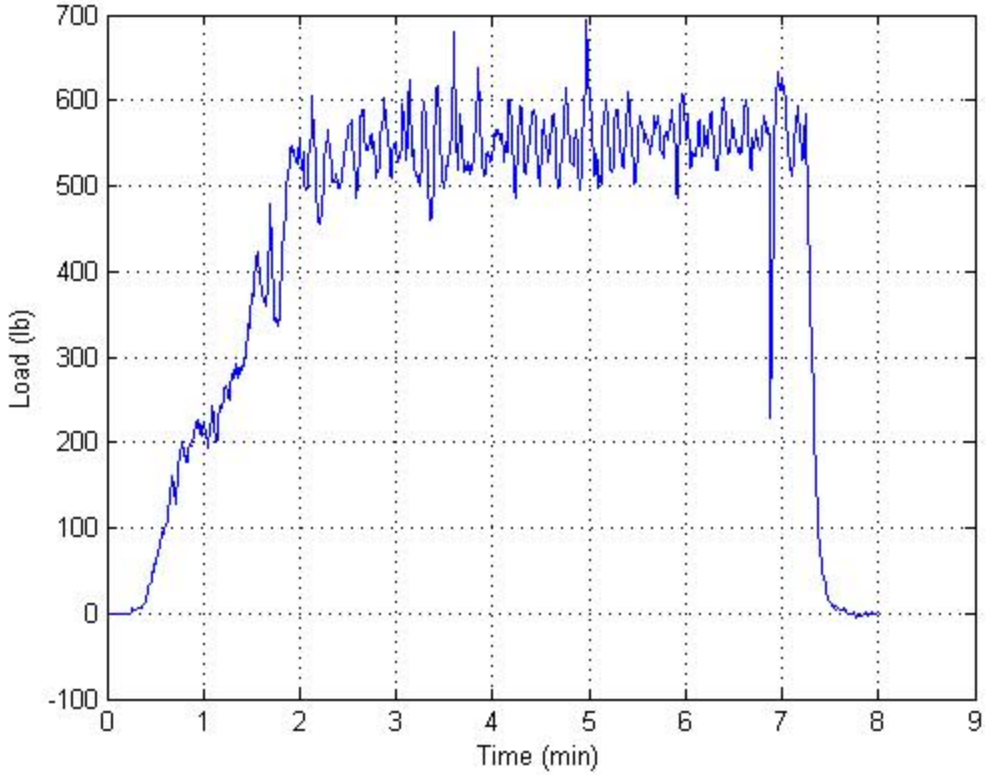
Time (min)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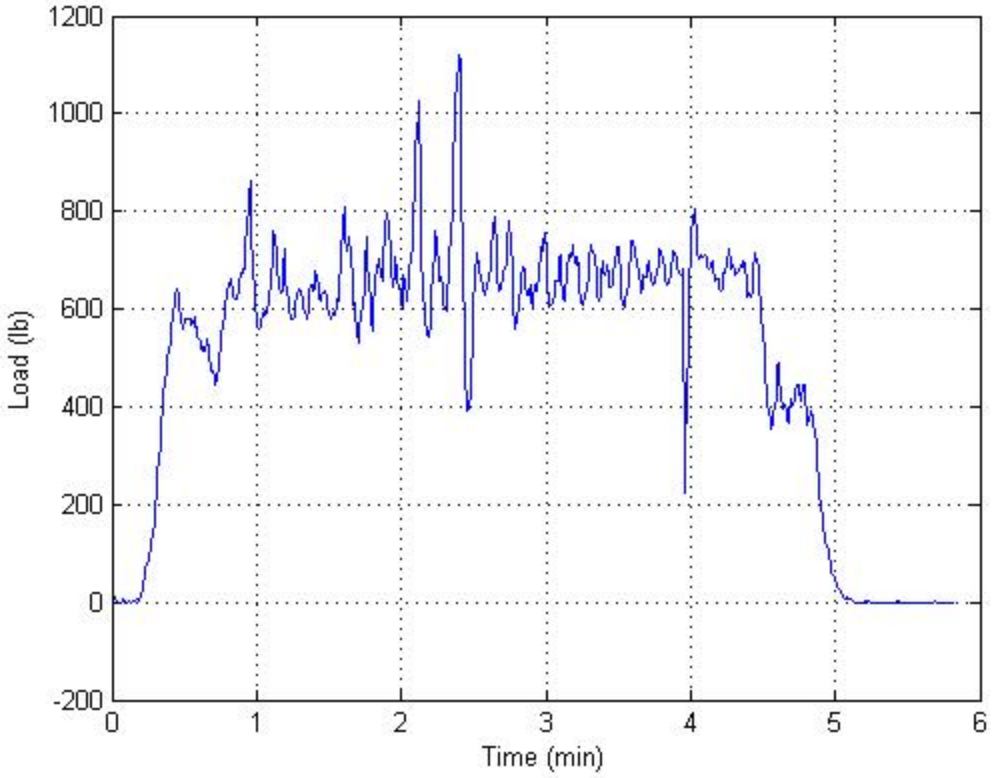
Time (min)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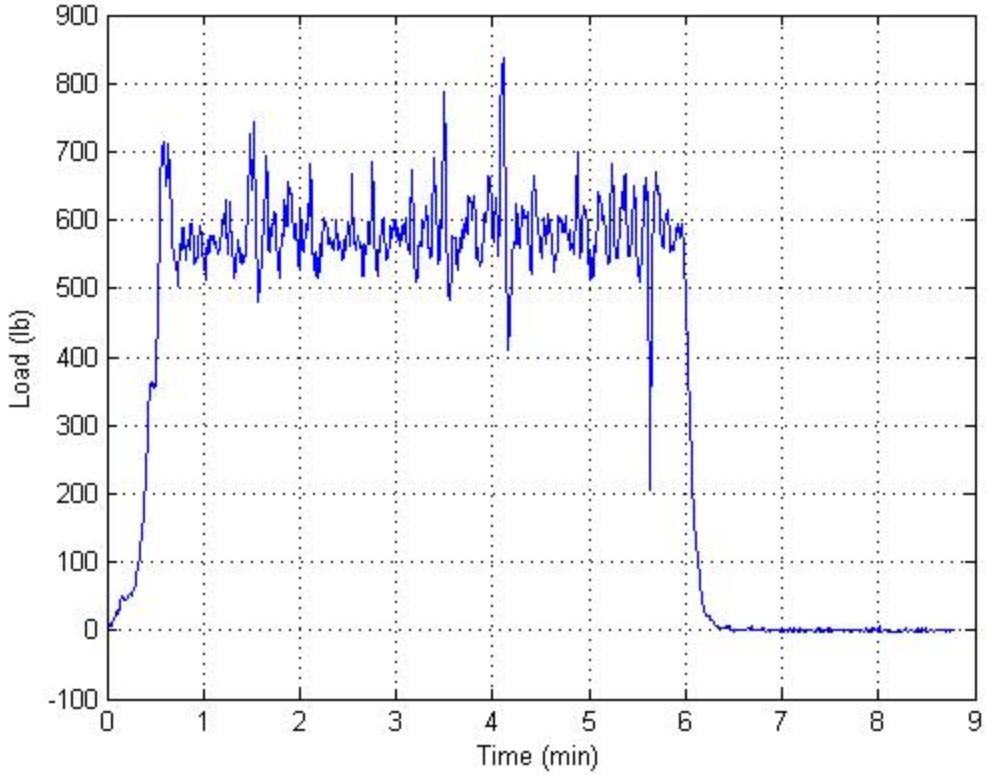
Time (min)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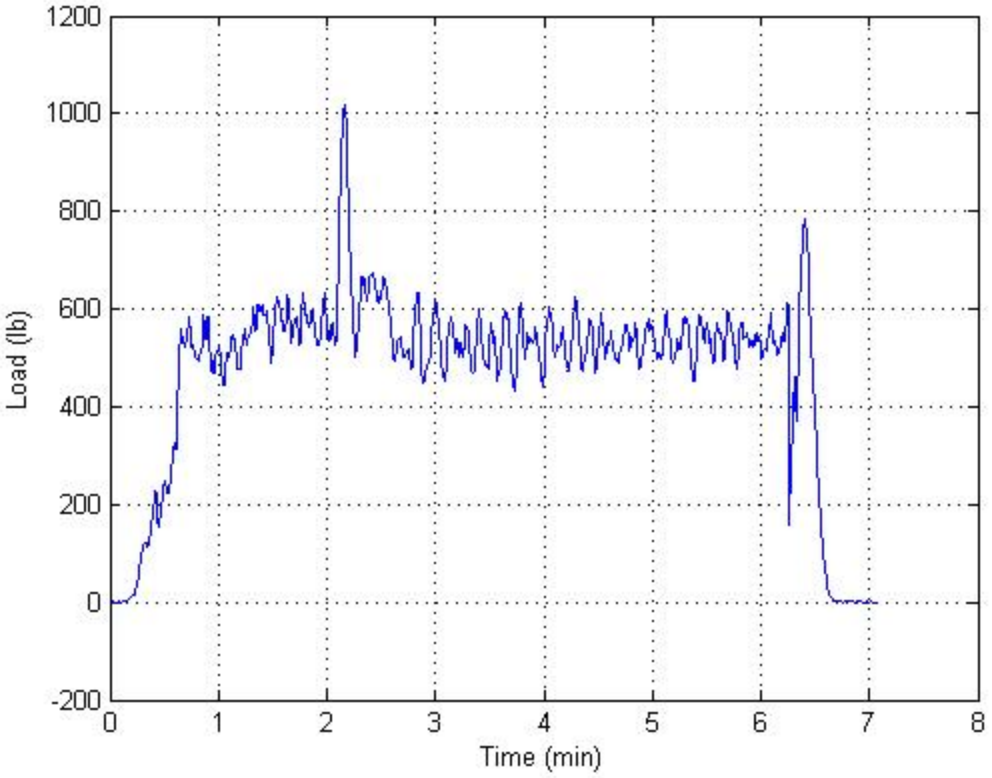
Time (min)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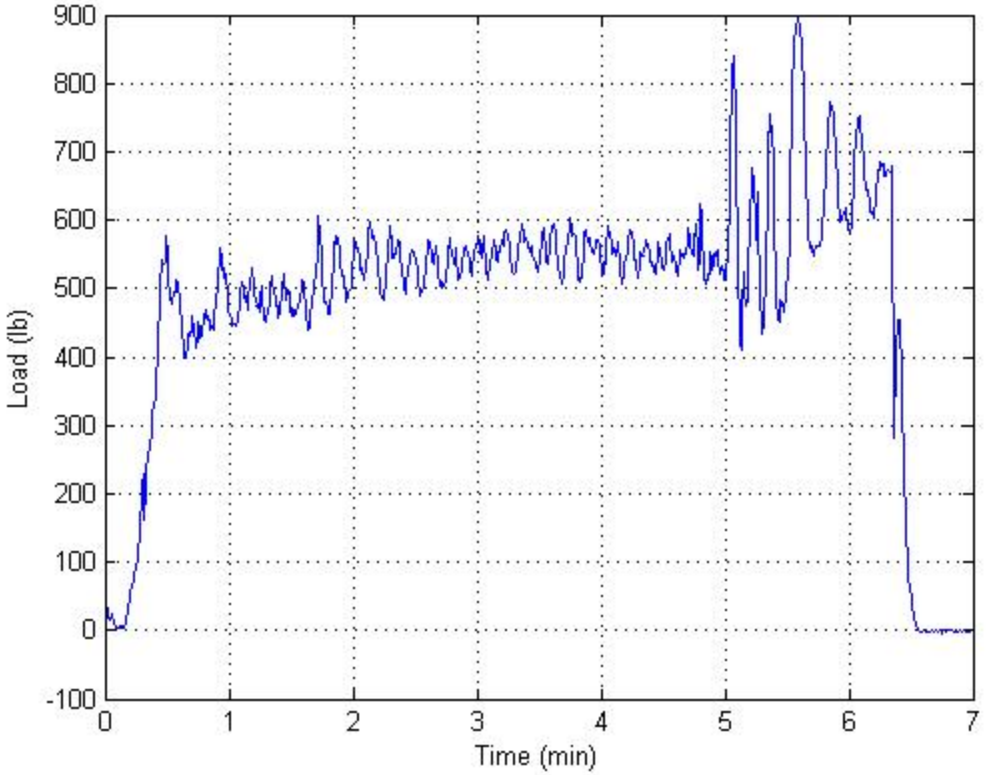
Time (min)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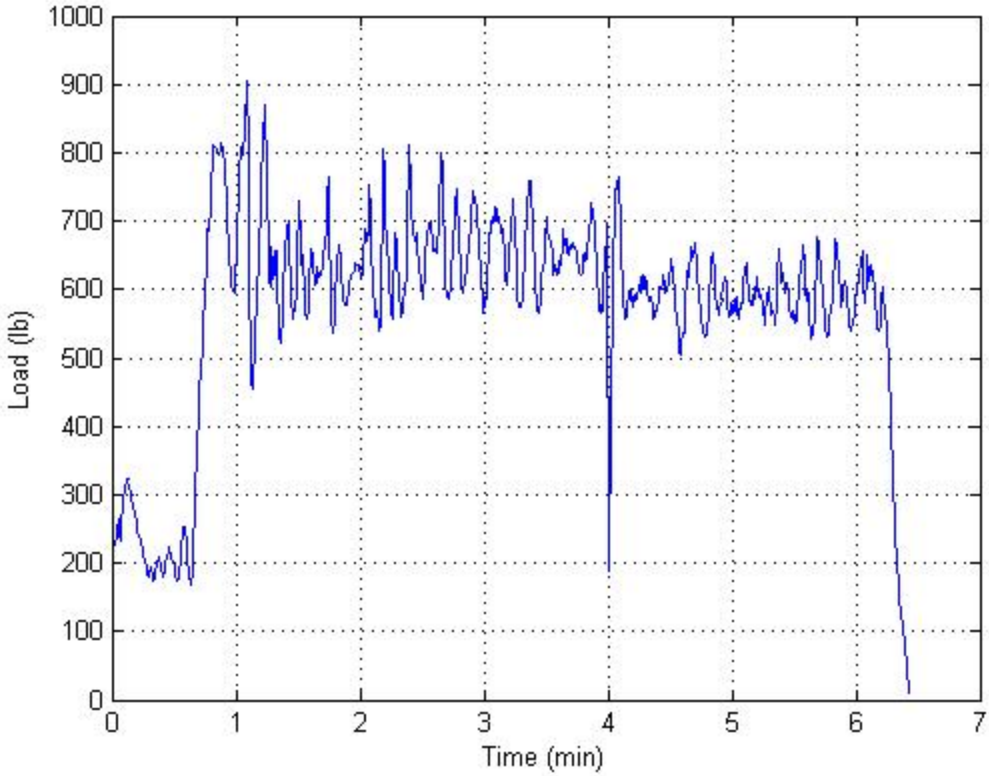
Time (min)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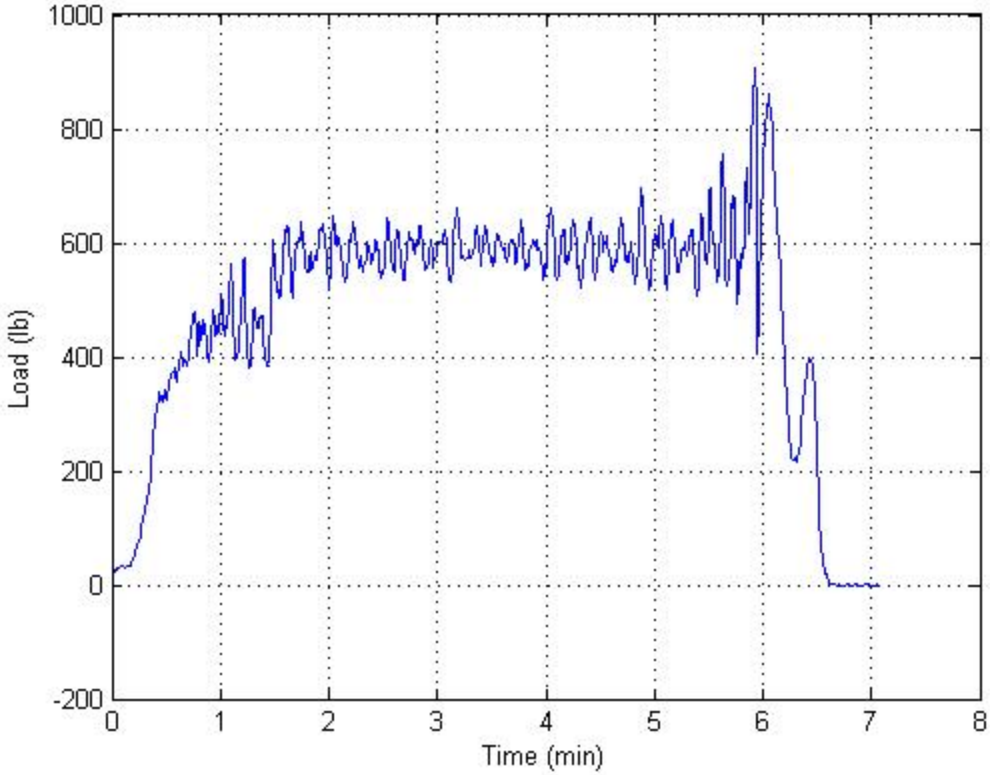
Time (min)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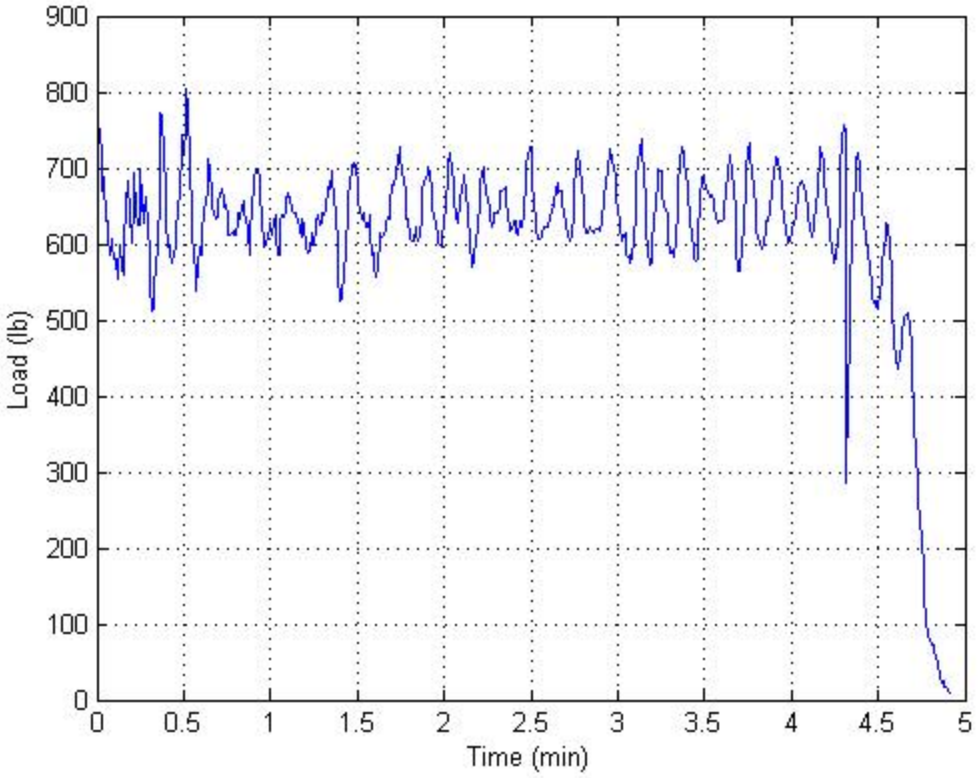
Time (min)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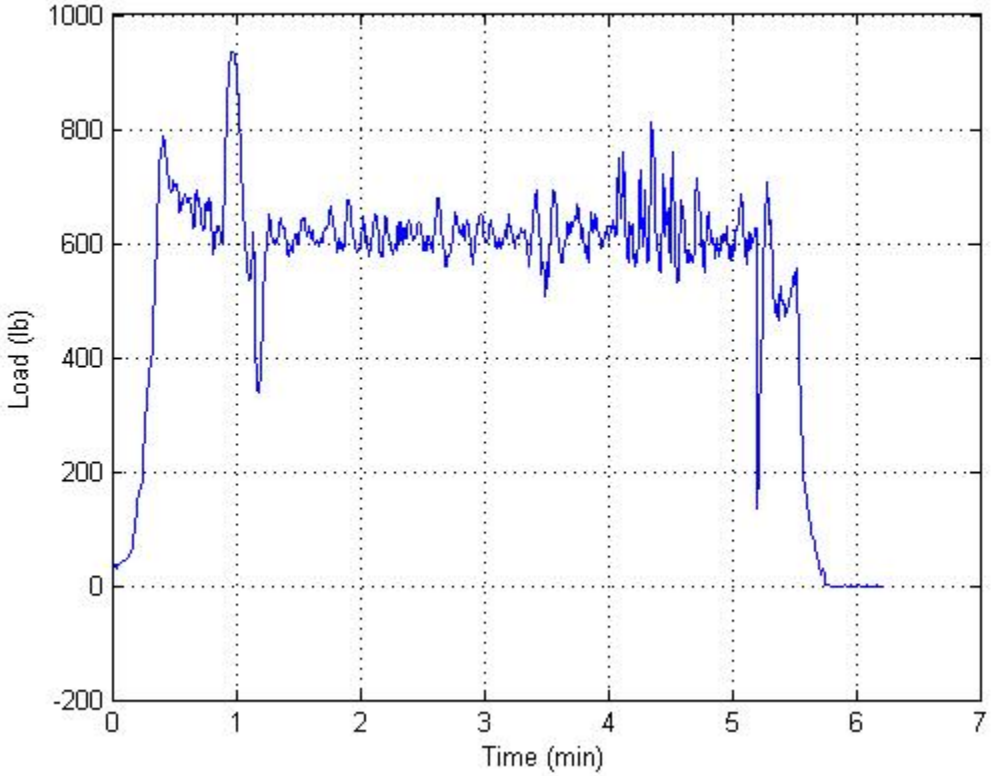
Time (min)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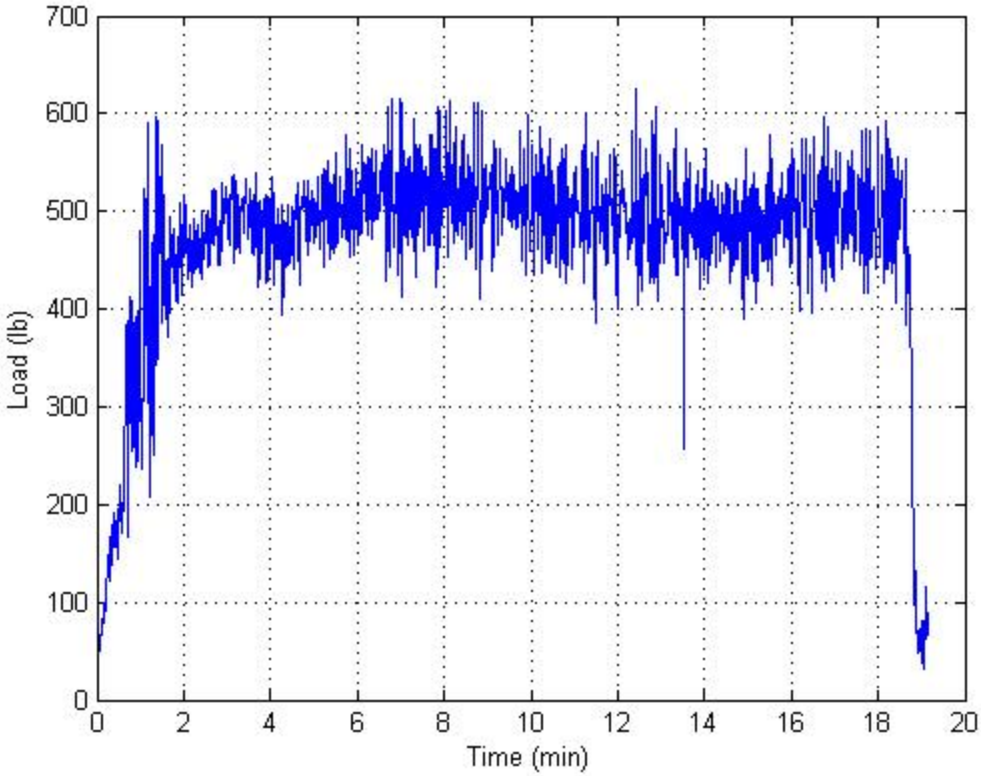
7
Time (min)

Load vs Time for all tow tests

07 09 08

A001 – A004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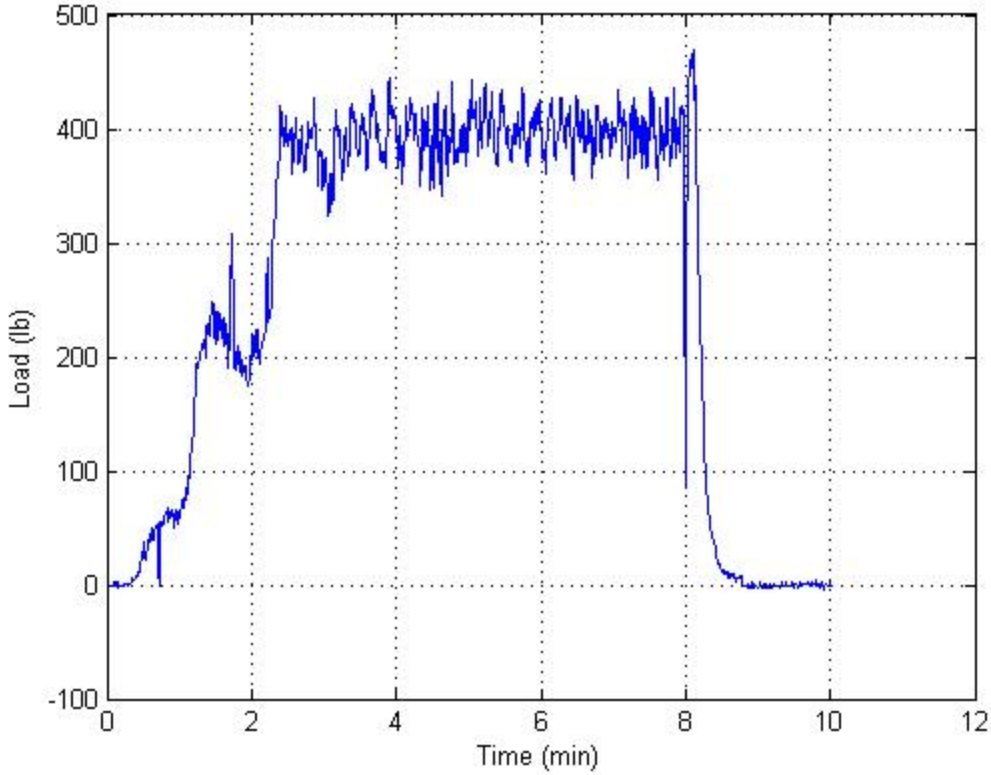
20
Time (min)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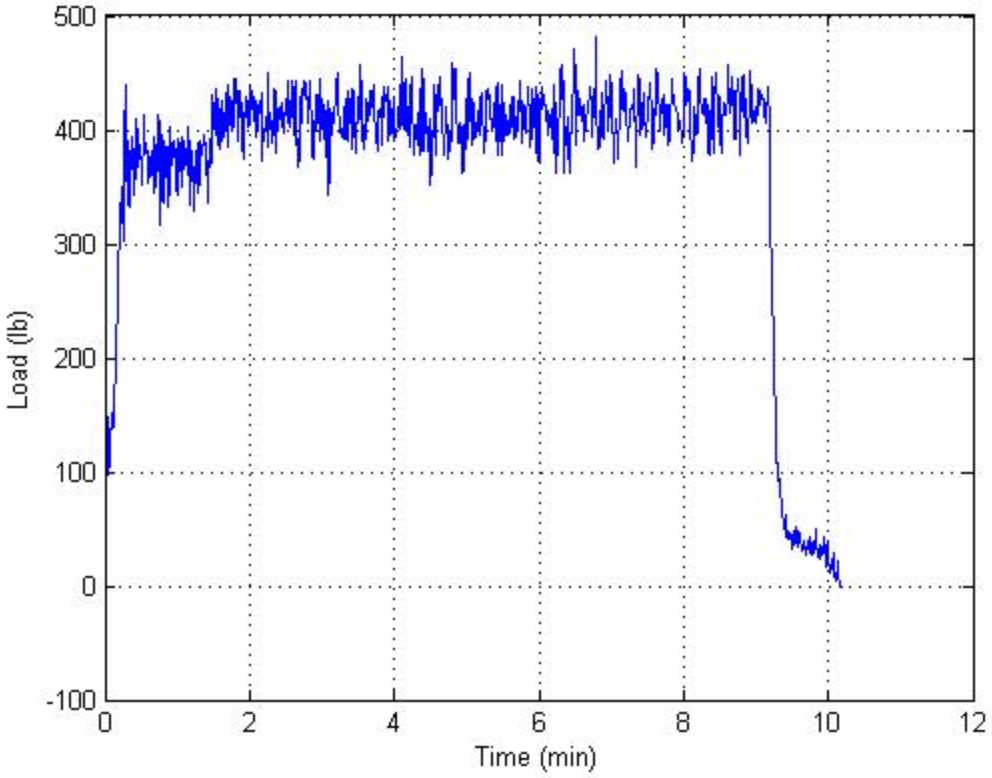
Time (min)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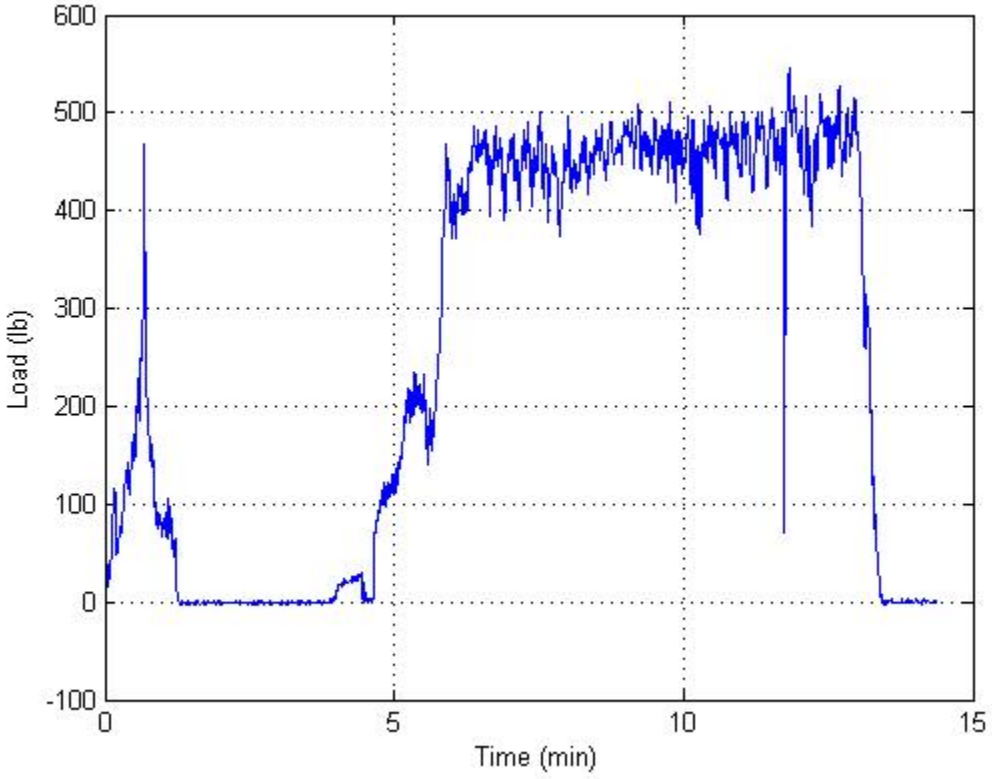
Time (min)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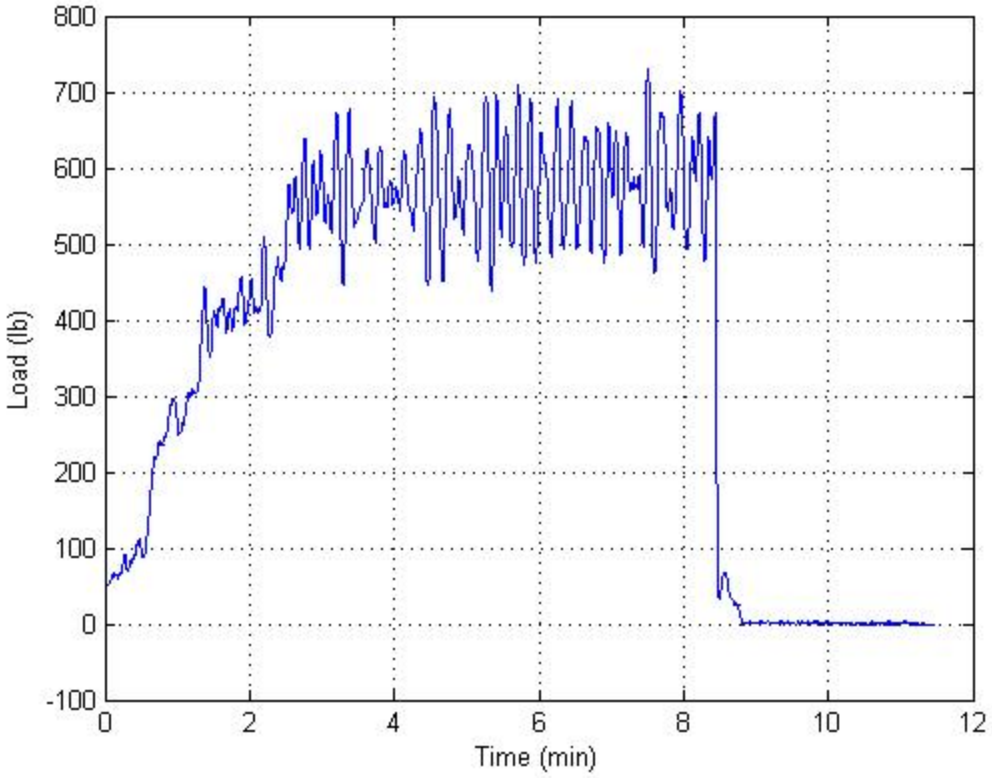
15
Time (min)

Load vs Time for all tow tests

07 16 08

A001 – A008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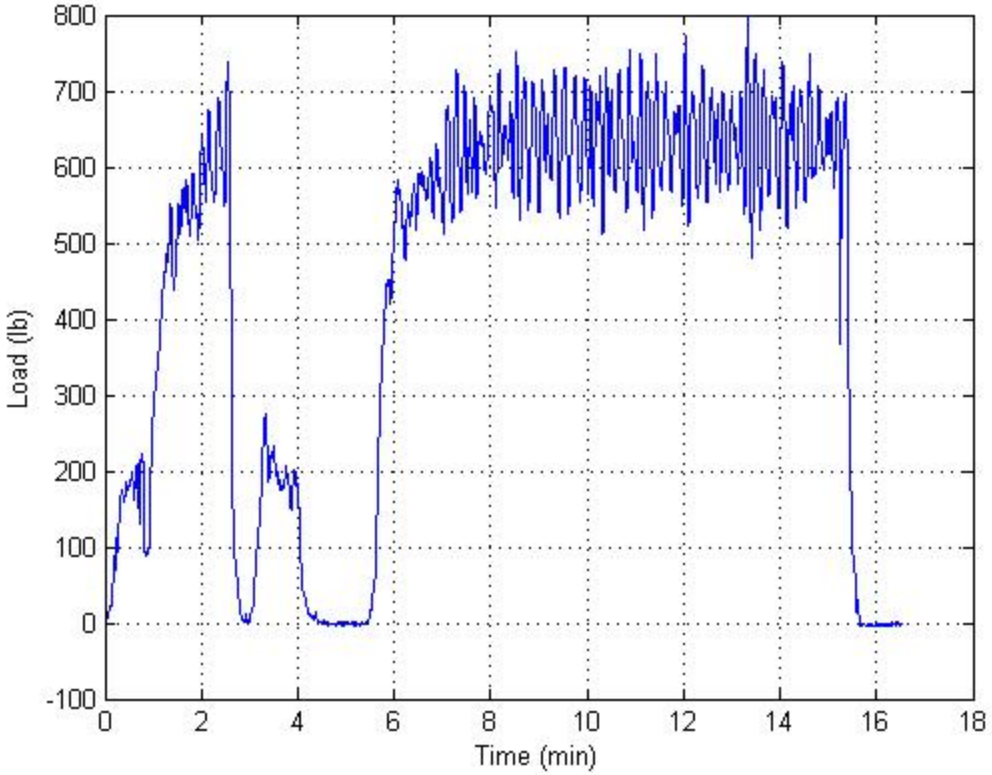
12
Time (min)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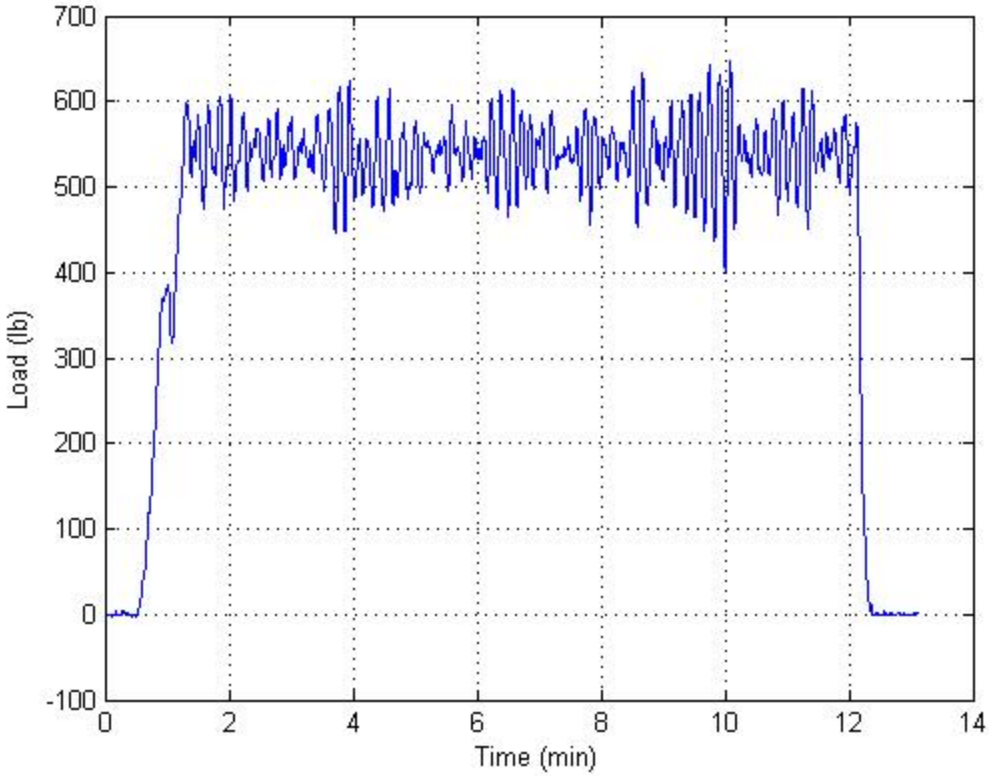
16
18
Time (min)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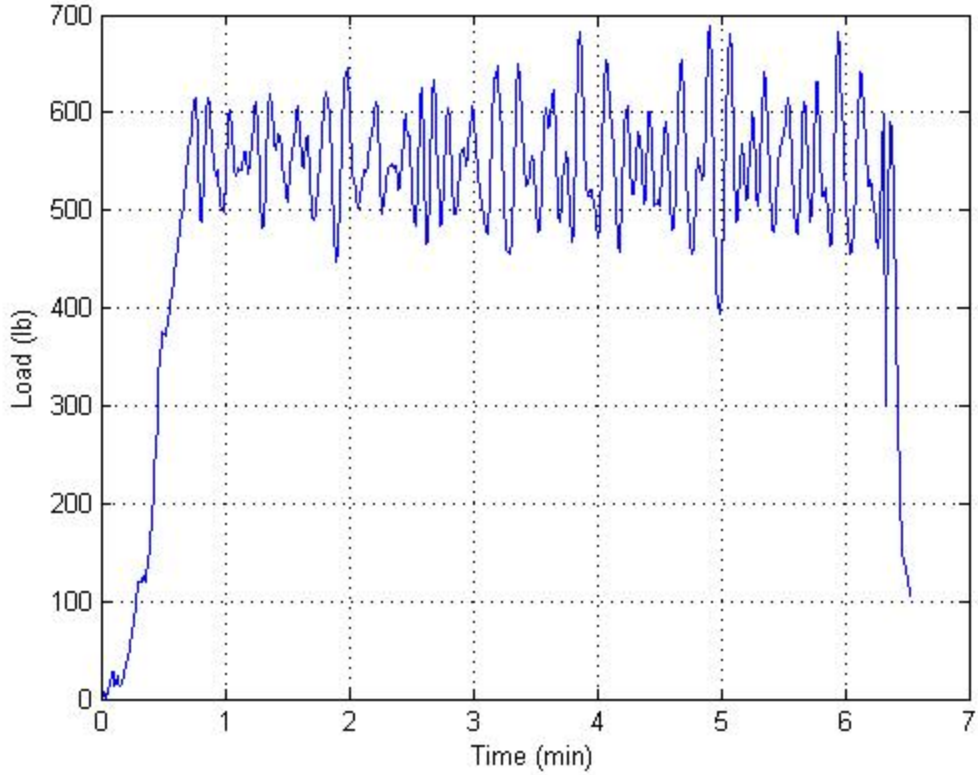
Time (min)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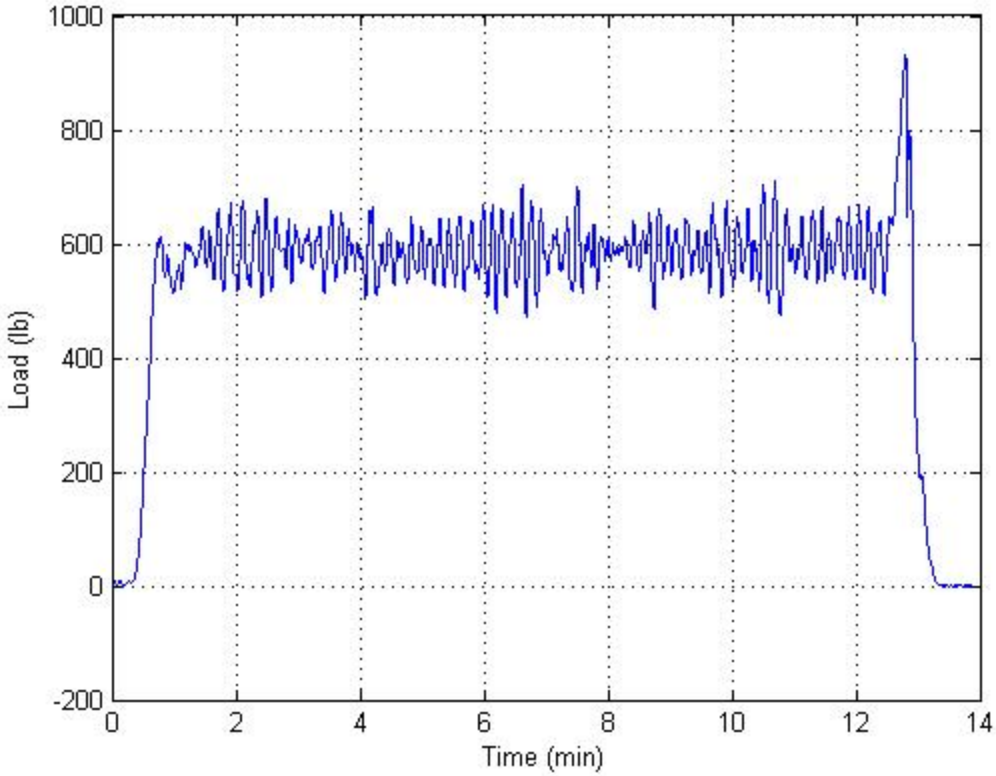
Time (min)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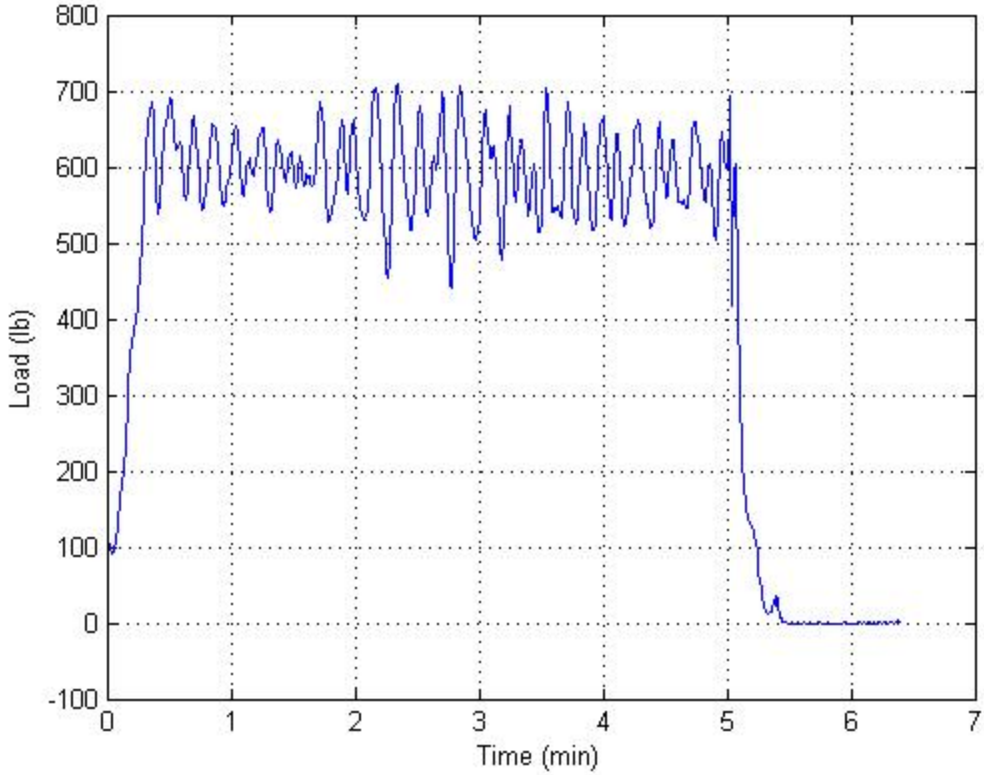
Time (min)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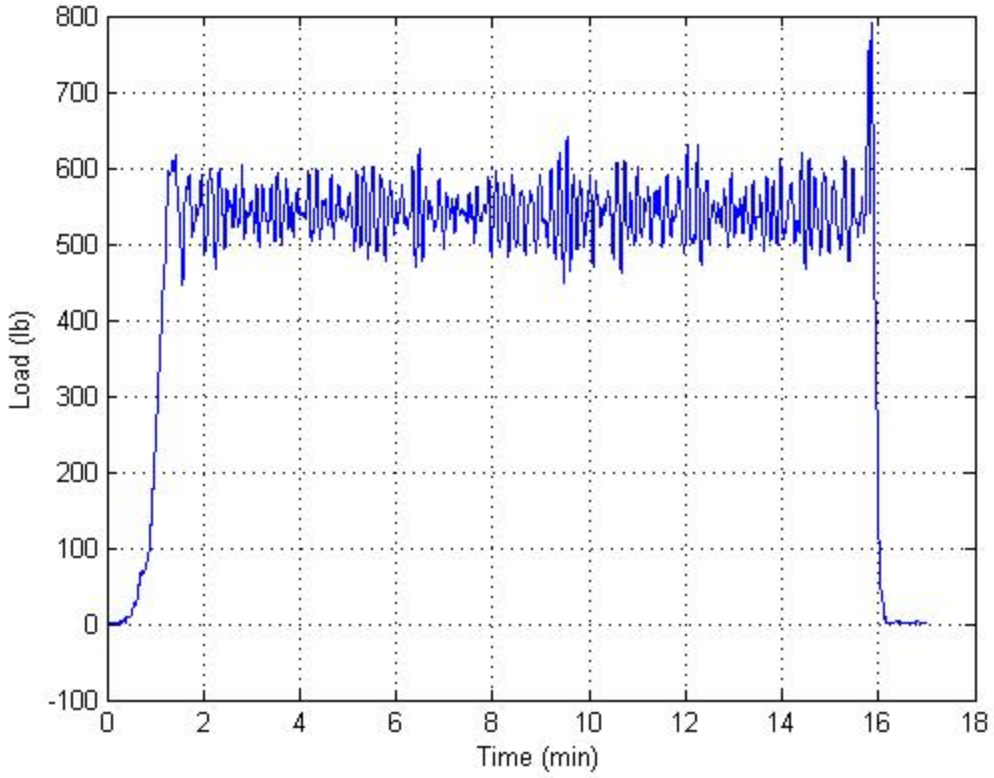
Time (min)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16
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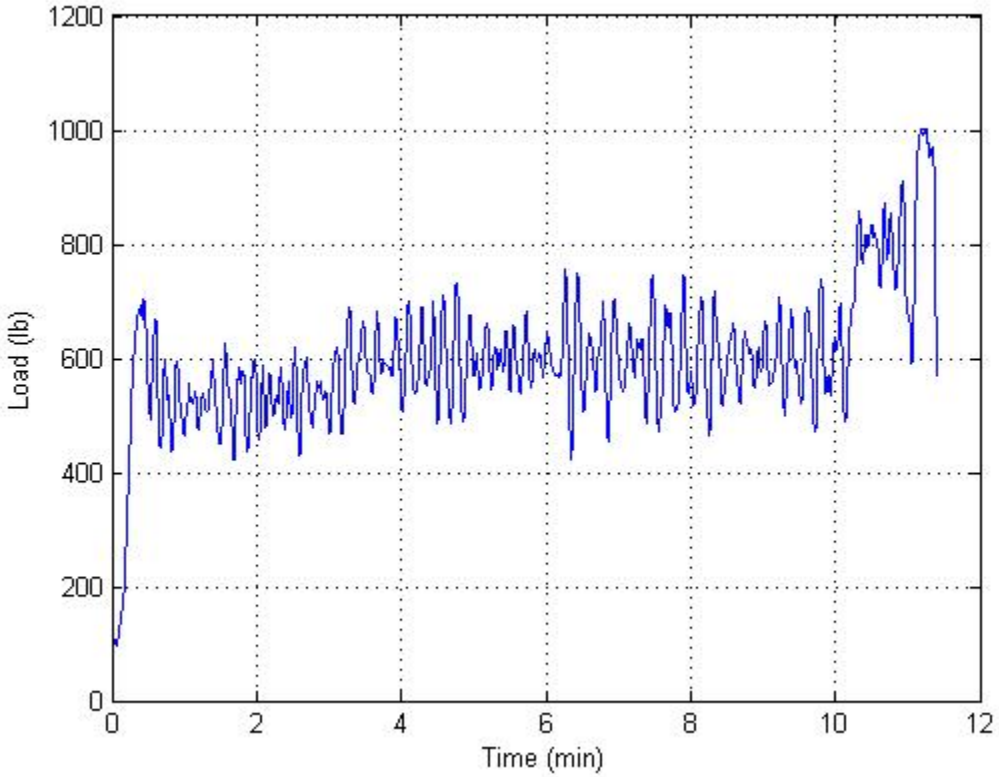
Time (min)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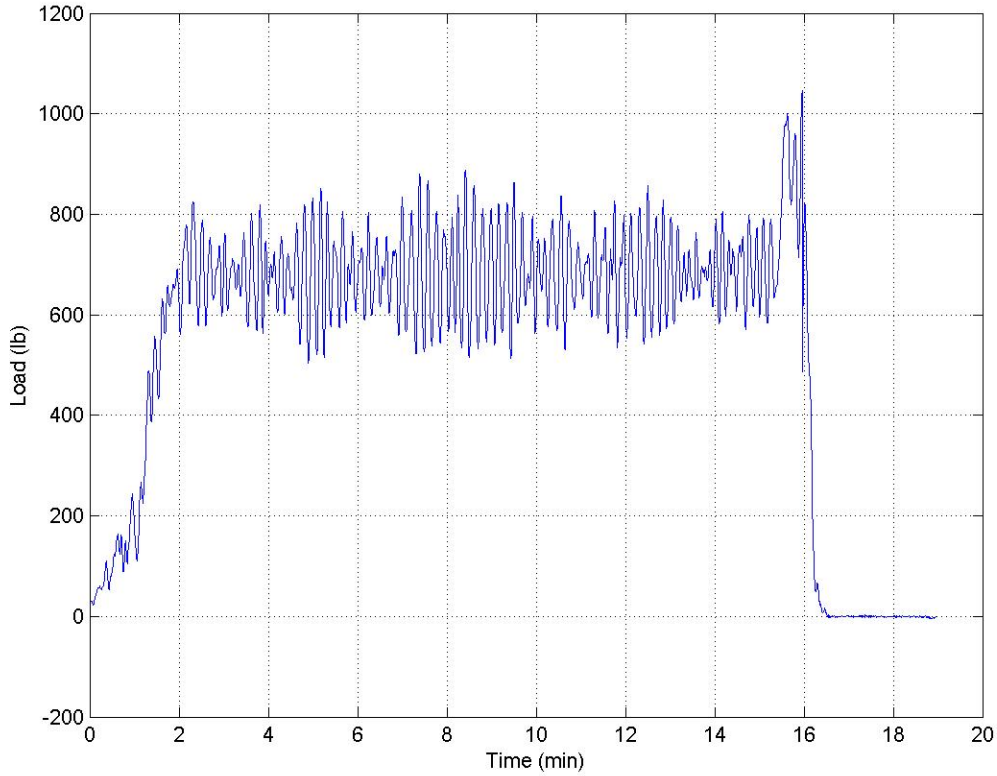
2
4
6
8
10
12
Time (min)

Load vs Time for all tow tests

07 17 08

A001 – A004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8
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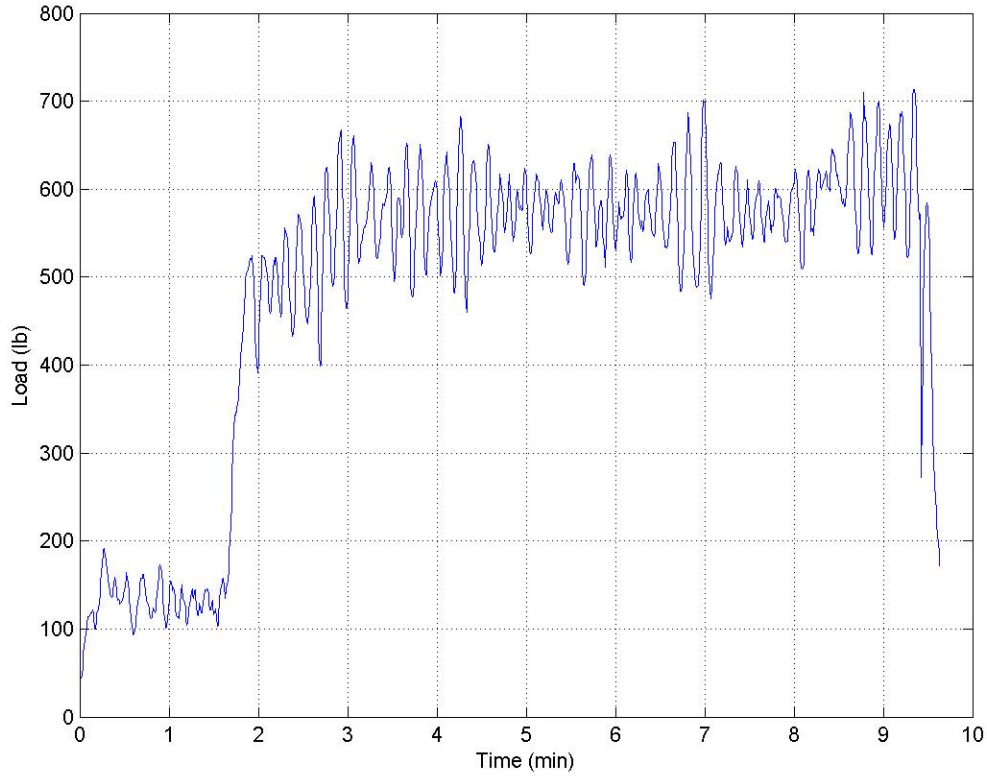
12
14
16
18
20
Time (min)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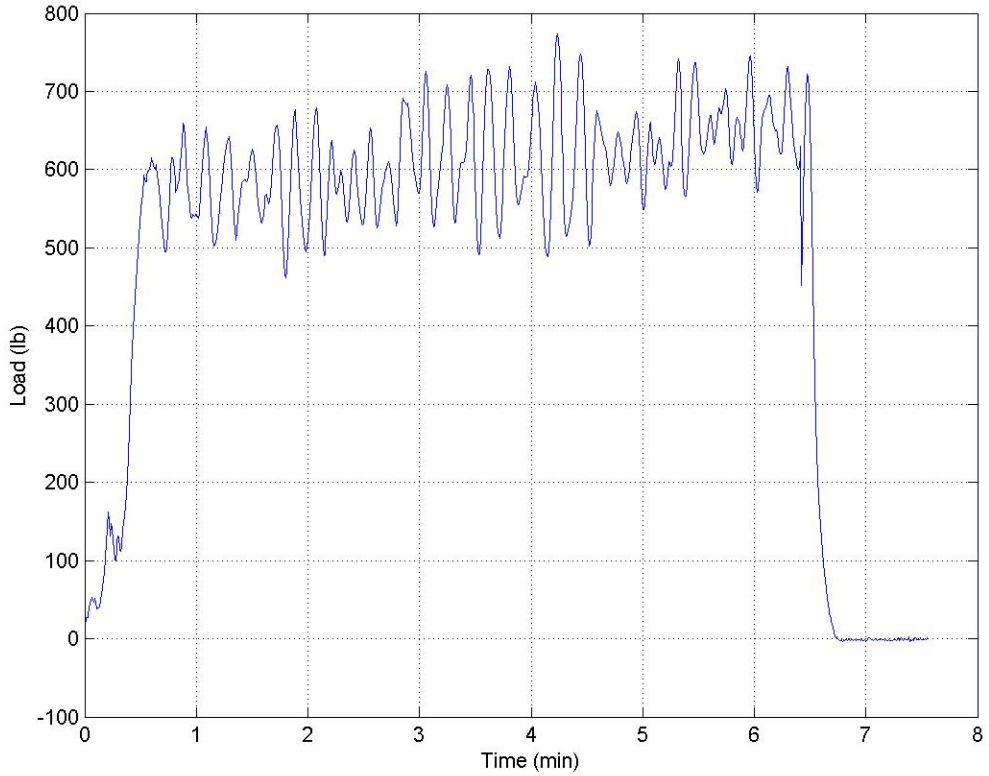
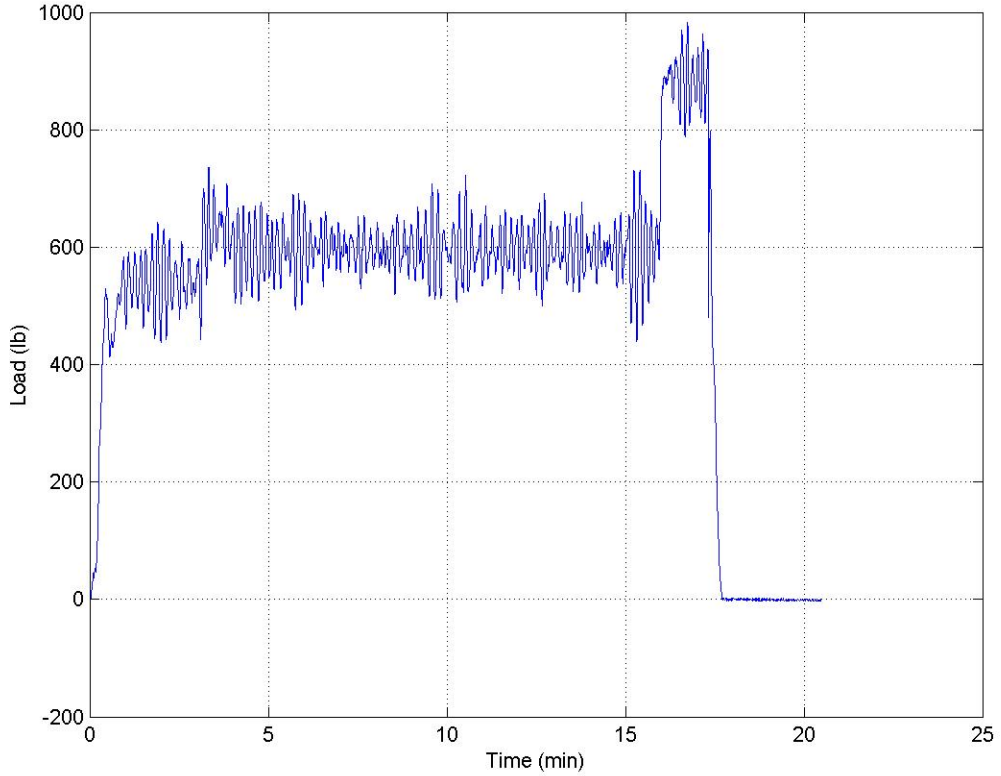
Load (lb)
0
1
2
3
4
5
6
7
8
9
10
Time (min)

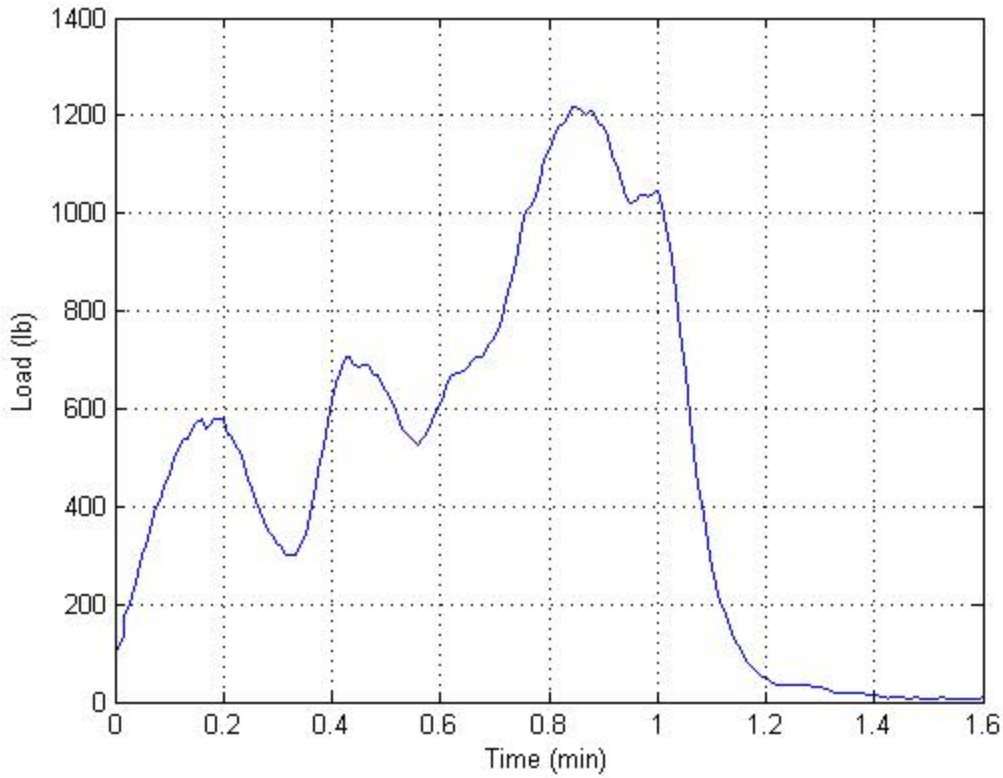

800
700
600
500
400
300
200
100
0
-100
Load (lb)
0
1
2
3
4
5
6
7
8
Time (min)

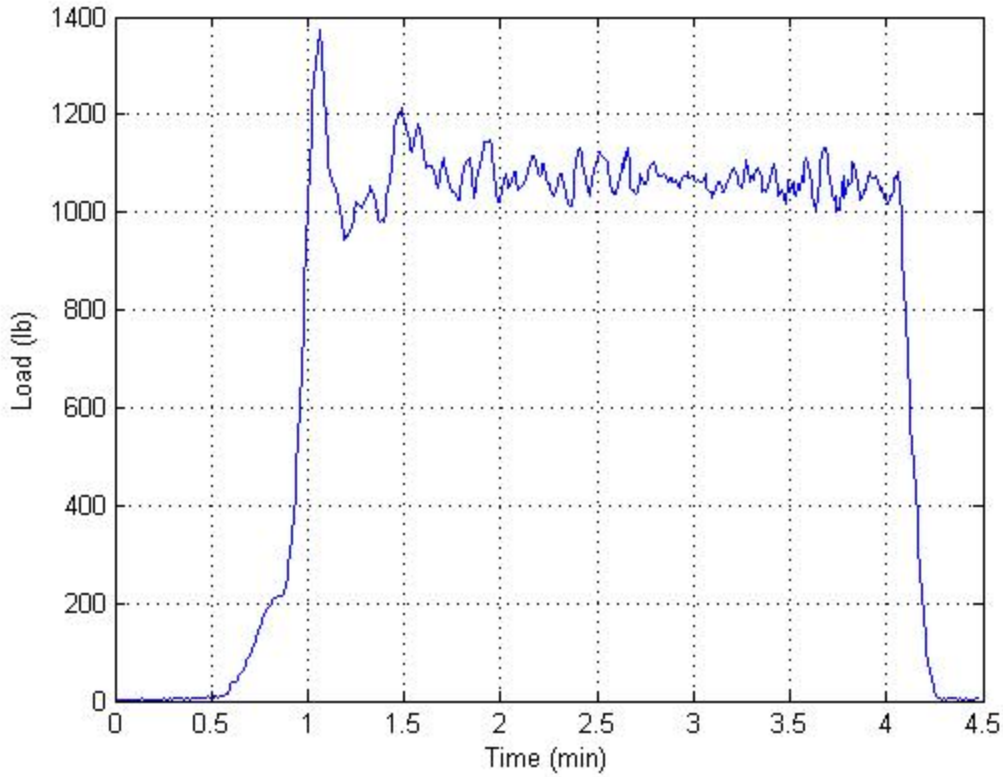

1000
800
600
400
200
0
-200
Load (lb)
0
5
10
15
20
25
Time (min)

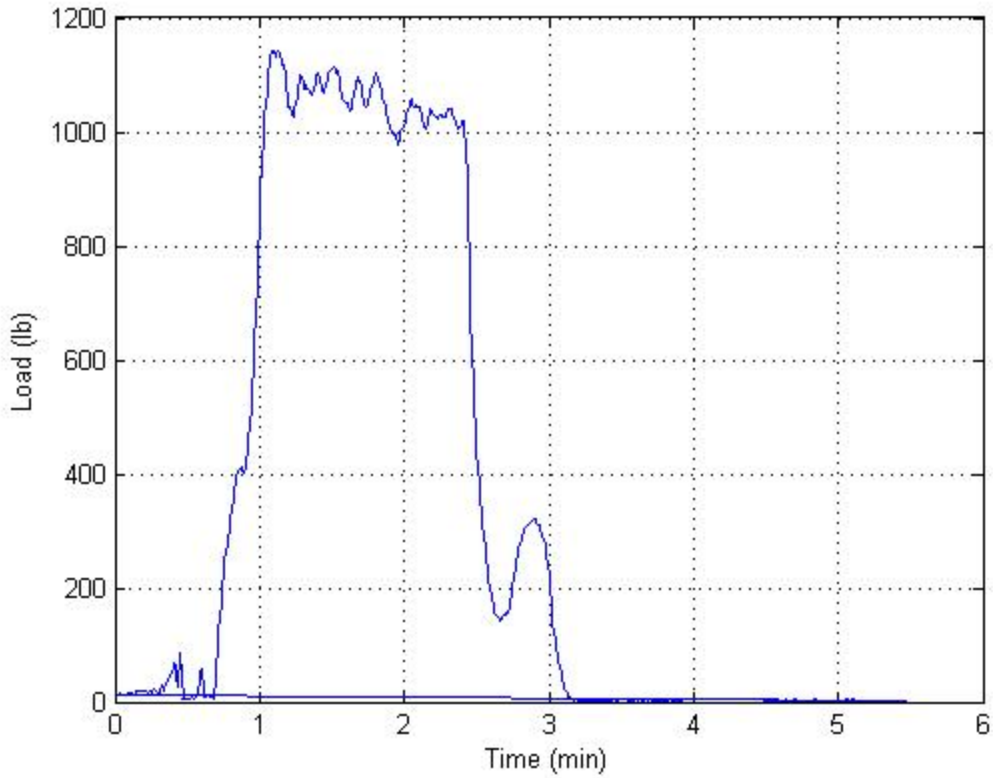
Load vs Time for all tow tests

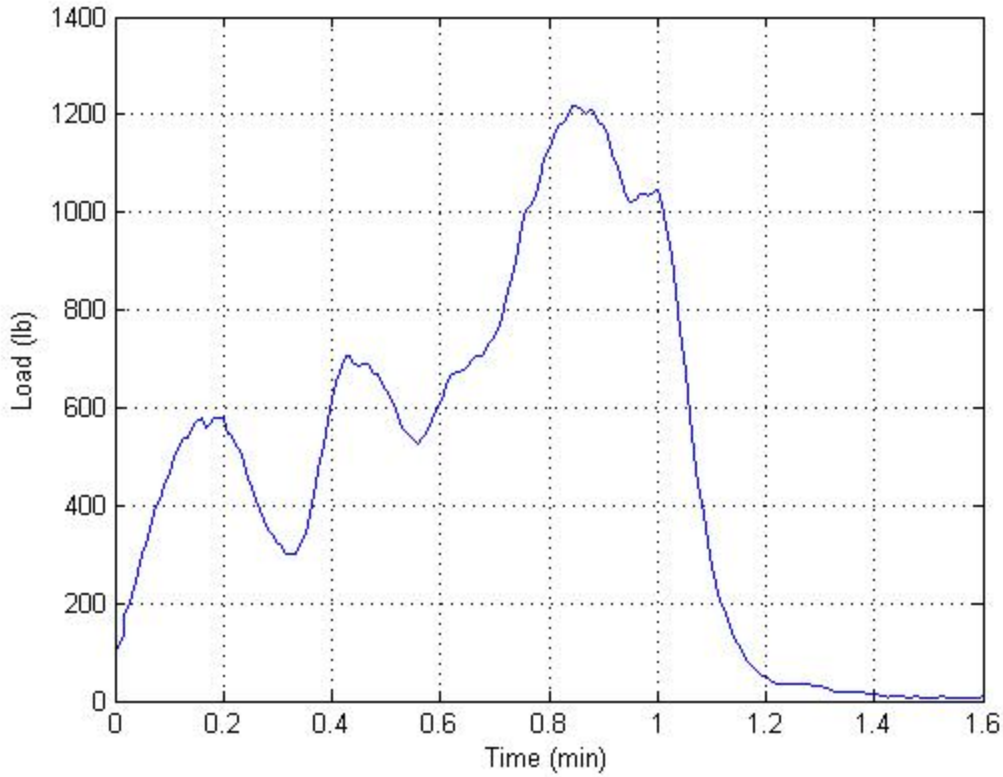
08 13 08

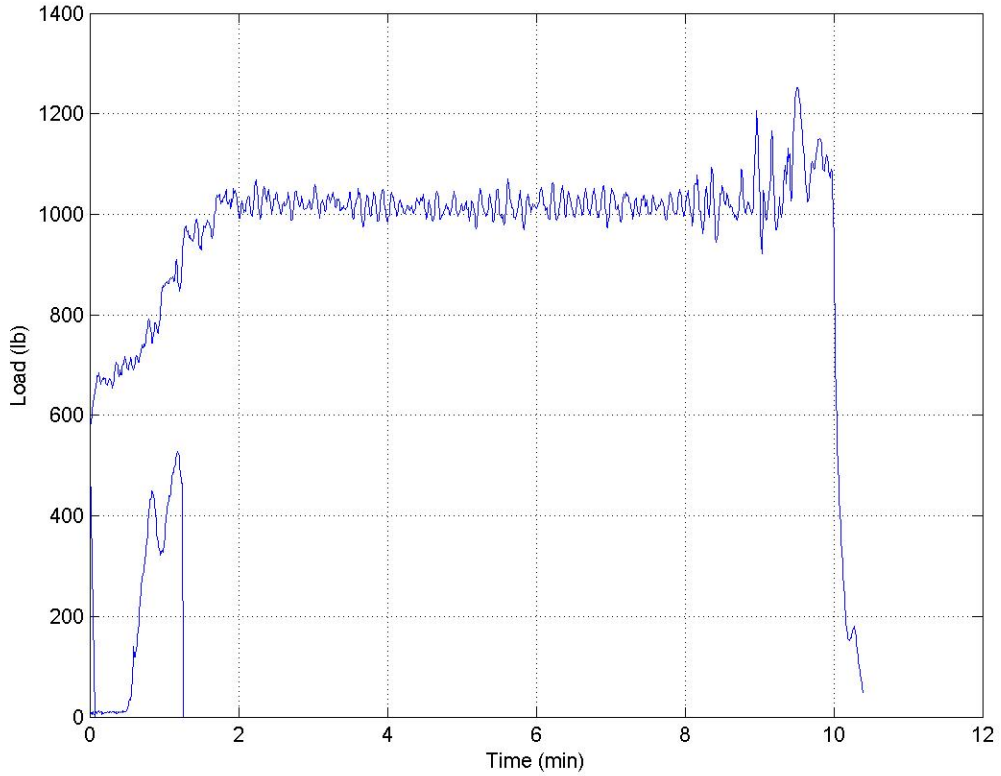
A001 – A010

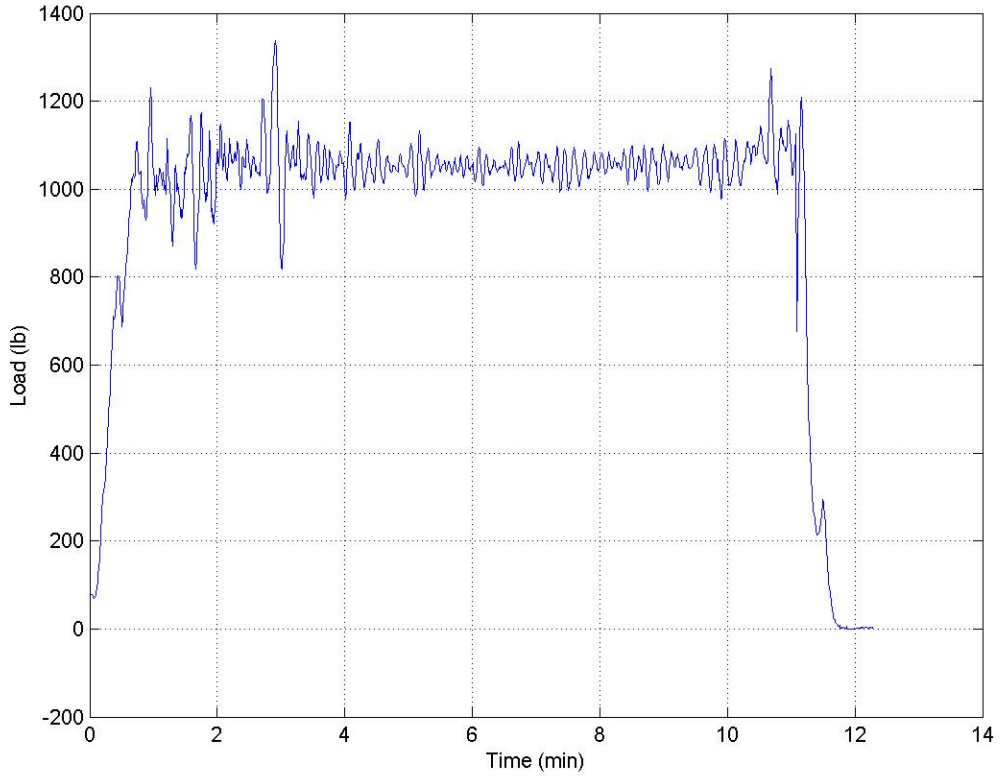

1400
1200
1000
800
600
400
200
0
Load (lb)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Time (min)

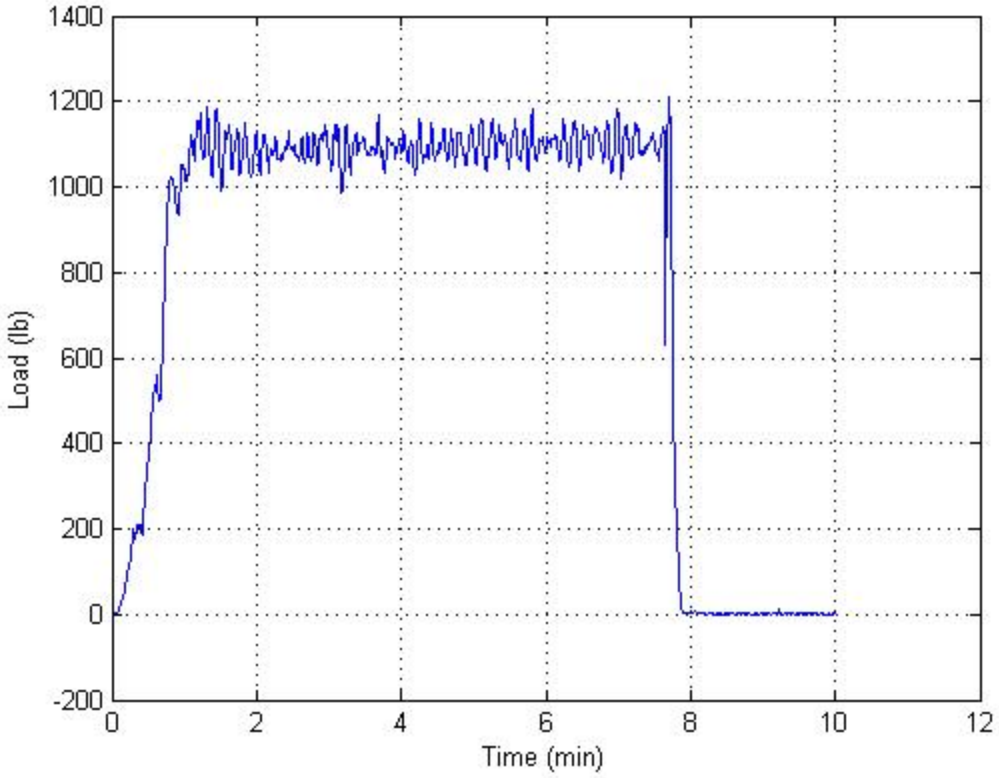

1400
1200
1000
800
600
400
200
0
Load (lb)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (min)

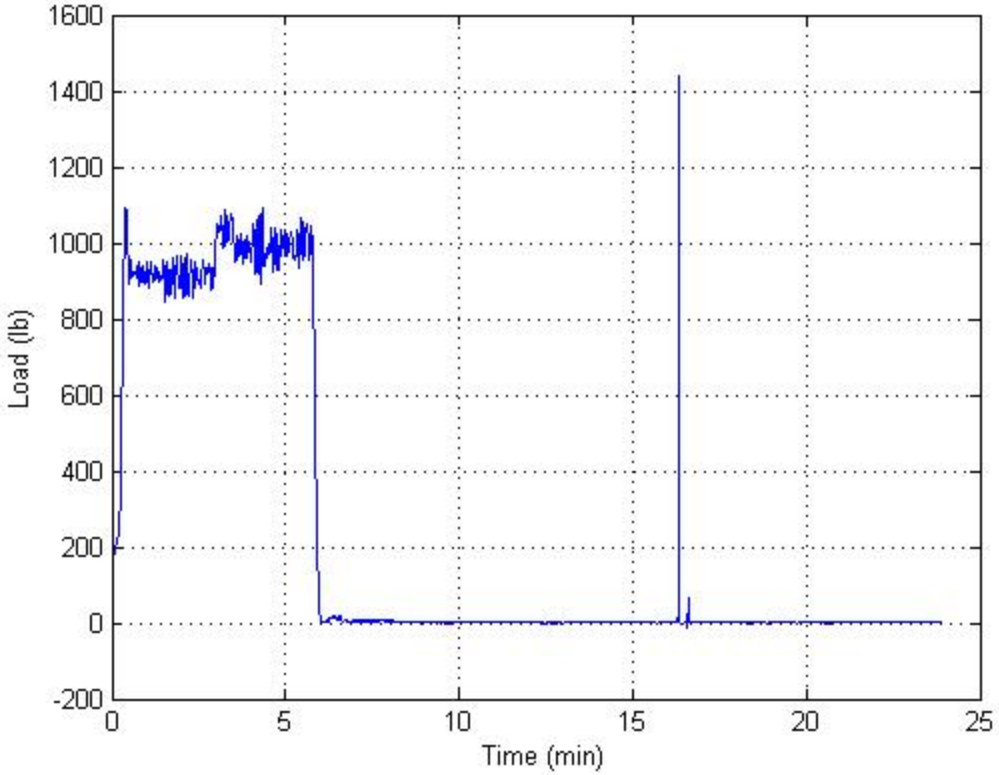

1200
1000
800
600
400
200
0
Load (lb)
0
1
2
3
4
5
6
Time (min)

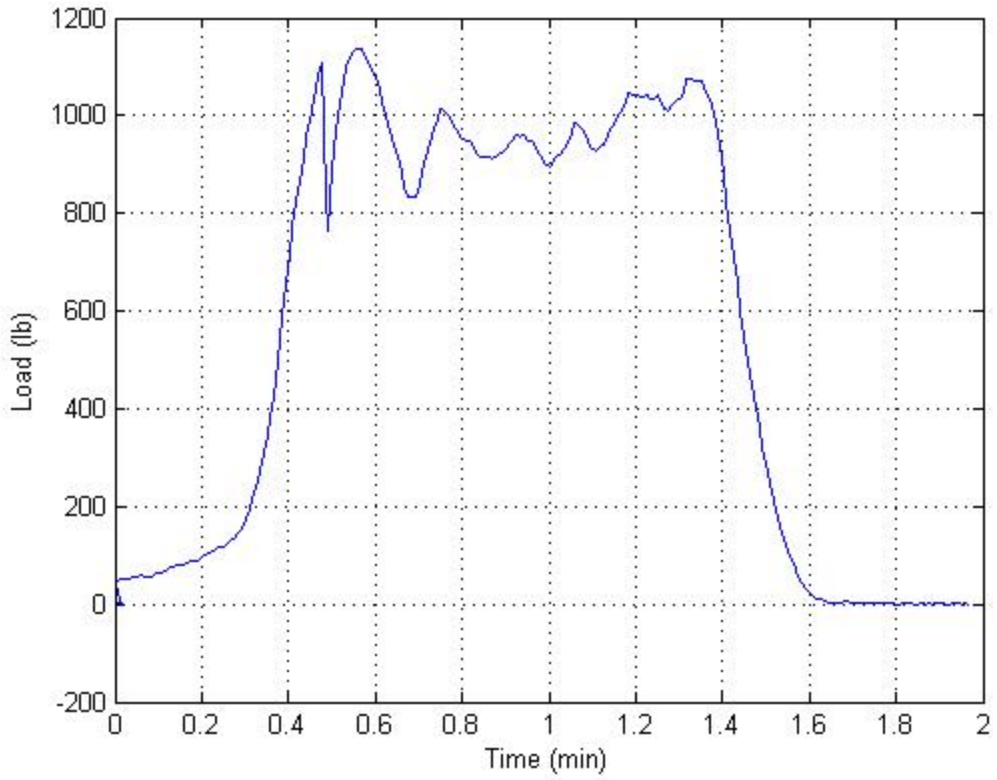

1400
1200
1000
800
600
400
200
0
Load (lb)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Time (min)

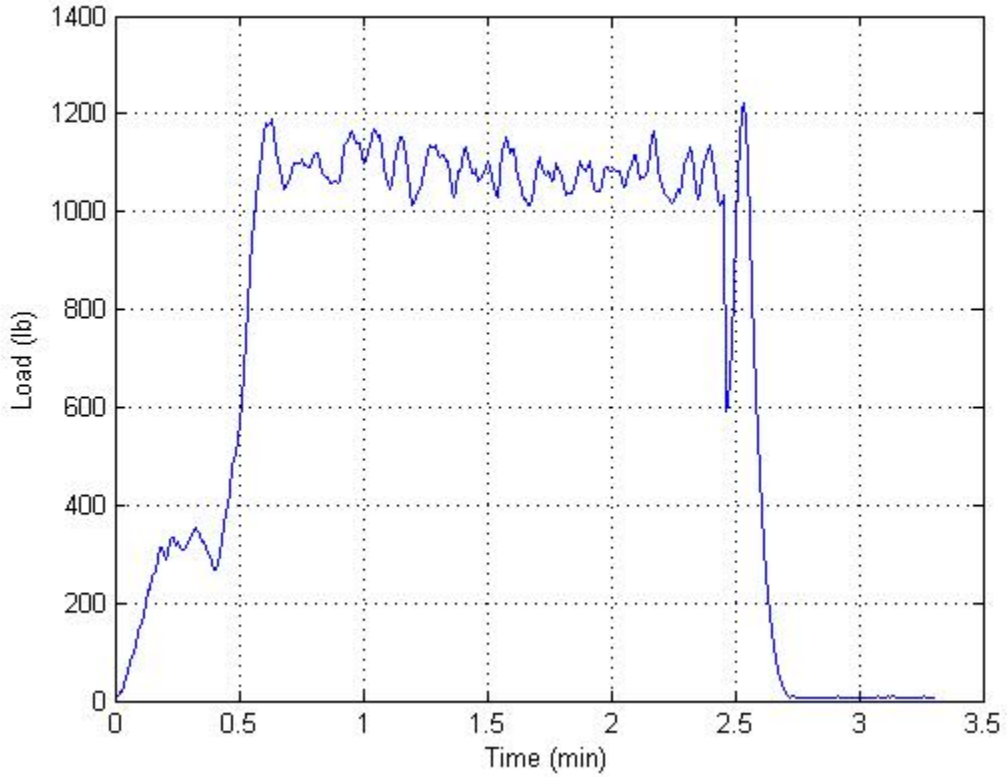

1400
1200
1000
800
600
400
200
0
Load (lb)
0
2
4
6
8
10
12
Time (min)


1400
1200
1000
800
600
400
200
0
-200
Load (lb)
0
2
4
6
8
10
12
14
Time (min)


1400
1200
1000
800
600
400
200
0
-200
Load (lb)
0
2
4
6
8
10
12
Time (min)


1600
1400
1200
1000
800
600
400
200
0
-200
Load (lb)
0
5
10
15
20
25
Time (min)


1200
1000
800
600
400
200
0
-200
Load (lb)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (min)


1400
1200
1000
800
600
400
200
0
Load (lb)
0
0.5
1
1.5
2
2.5
3
3.5
Time (min)

APPENDIX D

Pilot Study Log

TTLC Pilot Study Log

Vessel name: _____ Vessel operator: _____

Gear type: _____

TTLC/Trawl #	**# traps**	**Date/ Haul #**	**Depth (fm)**	**Bottom type**	**TTLC Band**	**Comments**
1				**M Sa Gr Rky**	**Gr Y R**	
2				**M Sa Gr Rky**	**Gr Y R**	
3				**M Sa Gr Rky**	**Gr Y R**	
4				**M Sa Gr Rky**	**Gr Y R**	
5				**M Sa Gr Rky**	**Gr Y R**	
6				**M Sa Gr Rky**	**Gr Y R**	
7				**M Sa Gr Rky**	**Gr Y R**	

8				**M Sa Gr Rky**	**Gr Y R**	
9				**M Sa Gr Rky**	**Gr Y R**	
10				**M Sa Gr Rky**	**Gr Y R**	

Table D-1. This is a summary of the line load and time to cut (ttc) for the tow experiments. The number of traps in the trawl and relative water depth are indicated for each day. **Shallow water** is 40-50 feet, **medium water** is 120-140 feet, and **deep water** is 230-250 feet.

				6/25/2008	**5 traps**	**shallow water**				
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
avg(lbs)	566	572	565	527	571	570	587	492	581	493
max(lbs)	633	642	655	667	722	742	747	712	742	797
ttc(min)	2.96	no ttlc	4.15	4.54	5.10	5.95	4.37	5.66	5.79	4.55

			6/27/2008	**5 traps**	**medium water**			
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

avg(lbs)	486	433	496	451	451	502	496	452
max(lbs)	707	764	634	560	597	562	647	575
ttc(min)	6.36	10.08	7.19	dull blade	8.04	dull blade	5.54	dull blade

				7/2/2008	**10 traps**	**medium water**				
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
avg(lbs)	509	628	573	538	542	596	549	630	611	627
max(lbs)	693	1119	837	1017	897	905	908	804	936	1057
ttc(min)	6.47	4.62	5.70	6.10	6.17	6.12	6.16	4.78	5.33	4.99

		7/9/2008	**5 traps**	**shallow water**
run	**1**	**2**	**3**	**4**
avg(lbs)	372	404	439	489
max(lbs)	469	482	546	626
ttc(min)	6.73	tangle	7.92	18.23

			7/16/2008					
			8	**10 traps**	**deep water**			
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
avg(lbs)	590	531	540	586	585	539	604	526
max(lbs)	795	648	688	931	709	790	1003	731
ttc(min)	11.92	11.45	6.04	12.53	5.01	15.03	11.27	broke endline

		7/17/2008		
		8	**10 traps**	**deep water**
run	**1**	**2**	**3**	**4**
avg(lbs)	562	603	605	676
max(lbs)	714	774	983	1045
ttc(min)	7.95	6.21	17.33	15.18

						medium			
				8/13/2008	**20 traps**	**water**			
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

avg(lbs)	947	1015	1047	930	875	937	947	830	673
max(lbs)	1252	1338	1212	1438	1139	1222	1372	1144	1219
ttc(min)	no record	11.40	7.47	transmission	7.09	2.53	ghost gear	ghost gear	ghost gear

Table D-2. This is a summary of bottom types fished during the pilot study. The bottom types are those shown in the log sheet below: M-mud, Sa-sand, Gr-gravel, and Rky-rocky.

	Boat 1				**Boat 2**		
M	**Sa**	**Gr**	**Rky**	**M**	**Sa**	**Gr**	**Rky**
0	0	10	0	2	2	4	2
0	0	7	3	0	5	4	1
0	1	3	6	0	2	3	5
0	1	3	6	0	4	5	1
0	1	3	6	2	3	3	2
0	1	2	7	2	1	4	3
0	1	3	6	2	2	4	2
0	0	3	7	2	2	4	2
0	0	5	5	2	2	4	2
0	0	5	5	2	2	4	2