PWSRCAC EMERGENCY TOWLINE DEPLOYMENT PRACTICAL TRIALS

Practical Trial Summary Report

PREPARED FOR:	BY:
Prince William Sound RCAC Valdez, Alaska	Kevin P. Raleigh PROJECT ENGINEER
Glosten 1201 WESTERN AVENUE, SUITE 200 SEATTLE, WASHINGTON 98101-2953 T 206.624.7850 GLOSTEN.COM	CHECKED: Peter S. Soles PRINCIPAL APPROVED: Justin M. Morgan, PE PRINCIPAL-IN-CHARGE

DOC:	REV:	FILE:	DATE:
21024.02	-	21024.01	6 August 2021

JUSTIN M. MORGAN, STATE OF WASHINGTON, 33972, REGISTERED PROFESSIONAL ENGINEER

Digitally Signed 06-Aug-2021

References

1. Tanker Towline Deployment BAT Review, Glosten, Rev. B, 12 May 2020.
2. Test Program Interim Report, Glosten, Rev. 1, 18 June 2021.

Executive Summary

A practical trial of devices for passing a towline between a disabled ship and a rescuing tug was conducted to better understand the practical characteristics of previously defined best available technologies. The trial tested four line throwing devices and one surface float line system. Each device was scored based on how safely and effectively it was able to deploy in a simulated emergency scenario.

The practical trial confirmed the abilities of some of the best performing devices and brought attention to aspects of device design that had not previously been evaluated, including device build quality and the effect of crosswinds on trailing shot lines/cordage.

The results of the trial and subsequent analysis showed that the highest scoring devices were the PLT-SOLAS and PLT-Multi manufactured by Restech Norway, followed closely by the Ikaros Line Thrower. The Samson Rope Technologies EVATS retrieving line system was tested and also performed very well in a deployment trial.

Background

In May of 2020, a report prepared for the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) evaluated the best available towline deployment technologies based on advertised device specifications (Reference 1). The report discussed the advantages and disadvantages of various devices designed to pass a small-diameter line between vessels. Based on the results of that report, a trial was proposed to practically test the highest-rated devices in a mock emergency scenario. A test program was proposed to PWSRCAC to evaluate each technology according to a set of practical criteria (Reference 2).

This report contains the details of the trial decided upon in the test program, a description of the trial itself, and the conditions of the event, as well as a presentation of the results of the test program and a discussion of the significance of the outcome to PWSRCAC.

Test Characteristics

Four line throwing devices and one surface float line system were evaluated:

- Restech Norway PLT-SOLAS pneumatic line thrower.
- Restech Norway PLT-Multi pneumatic line thrower.

- Delmar Safety/Bumerang BLT 250 Pneumatic Line Thrower.
- Hansson Pyrotech/Ikaros Line Thrower pyrotechnic device.
- Samson Rope Technologies EVATS retrieving line system – paired with a representative (mock) synthetic towing hawser.

The practical performance of each device was evaluated on four aspects of performance: ease of use, effectiveness, reliability, and safety. Each aspect was further broken down into specific device criteria and a scoring system was developed for objective analysis of each device. The breakdown of criteria decided upon prior to the trial is as follows:

- Ease of Use:
  - Ergonomics.
  - Weight.
- Effectiveness:
  - Range.
  - Accuracy and wind deflection.
- Reliability:
  - Range uniformity.
  - Ease of reload.
- Safety:
  - Firing control.

For the surface float line, the criteria of interest are as follows:

- Behavior of deployed surface line.
- Ease of retrieval.
- Time to complete retrieval operations (connection of towline to tow wire on tug).

In addition to the line throwing device criteria discussed in the interim report (Reference 2), this report also discusses two additional criteria recognized upon practical deployment: device build quality and shot line/cordage deflection independent of projectile flight-deflection.

Conditions on the Date of the Trial

The trial was conducted on Tuesday, 15 June 2021. The final date was chosen for predicted moderate wind speeds, which allowed for projectile deflections in crosswinds, and minimal chance of precipitation, which enabled drone flight for aerial videography. All tests took place in central Puget Sound, east of the traffic separation scheme between Meadow Point and Point Wells. The trial made use of two azimuthing stern drive (ASD) tugs, T/V *Bering Titan* and T/V *Mariner*, and a flat-deck cargo barge, *Kenai Trader*, chartered from Alaska Marine Lines. The principal characteristics of each vessel are presented in Table 1.

Table 1 Tug and barge general characteristics

Vessel	*Bering Titan*	*Mariner*	*Kenai Trader*
Length (ft)	120	80	285
Beam (ft)	35	32	78
Horsepower	5000	4000	-

The barge was used (in an empty condition) to simulate a disabled oceangoing vessel in a free drift state. One tug was made up to the barge to control its movement and heading while the second tug performed the role of the responding emergency towing vessel, or rescue tug. The tugs have been designated as the Control Tug, referring to T/V *Mariner*, and the Emergency Towing Vessel (ETV), meaning T/V *Bering Titan*, for the purposes of this report.

The trial was attended by four Glosten engineers, two photographers/drone operators, representatives from each device manufacturer, a member of the PWSRCAC, a representative from Alyeska Pipeline Service Company, and the crew of each of the chartered tugs. The day of the trial, representatives from each device manufacturer were given the opportunity to prepare their device to be tested and provide input for best practices to ensure successful deployment.

For repeatability, a digital inclinometer was fitted to each device to measure its angle of inclination. For the Ikaros device, the inclinometer was held alongside its horizontal reference line to ensure a proper angle. A handheld laser range finder was used to confirm the distance between the ETV and the barge, and the tugs' anemometers were used to obtain and record wind speed data. Additionally, all devices were activated/fired from the same position on the ETV, with the pneumatic devices held against a padeye welded to the deck, as shown in Figure 1, and the pyrotechnic device fired while standing beside it. Each device was fired according to the procedure described in the Test Procedure section of this report. The Ikaros pyrotechnic device was fired with and without a buoyant head fitted on the projectile.

Figure 1 PLT-SOLAS being fired from padeye installed on the ETV aft deck

Test Criteria

Prior to the towline deployment trial, an interim report was developed and distributed containing a description of the tests to be performed, the criteria being evaluated, and the reasoning behind those criteria. The following section describes the test criteria that were analyzed, the way each criterion was scored, and the rubric used to develop overall scores for each device. Following the rubric is the final test procedure as followed on the day of the trial.

Test Criteria Evaluated – Line Throwing Devices

Ergonomics

Ease of use is critical during emergency operations where efficiency and timeliness are often critically important. Each device was evaluated based on the impact of its design (the body of the launching device itself) on accurately aiming and firing the projectile. The score for this criterion was determined on a scale from 1 to 3, with a score of 1 representing a device whose design hampers an operator's ability to hold, take aim, and resist device recoil, and a score of 3 representing a device whose design assists an operator in performing these actions with ease. SOLAS requires that devices be able to be fired while wearing working gloves and this was considered in the evaluation of ergonomics.

Weight

As with ergonomics, weight was evaluated as part of a combined ease of use score. Each device received a score between 1 and 3 corresponding to the effect that its weight had on successful device operation. A score of 1 corresponds with a device that weighs enough to negatively impact operator aim and/or firing, or one that does not weigh enough to aid control during firing.

Range

It is important during rescue operations, particularly in higher sea states, that a rescuing vessel is not forced to approach too closely to the disabled vessel; therefore, achieving a distance close to the maximum rated distance is a necessary criterion. Each line throwing device is rated to fire a projectile at least 230 meters. Accounting for the height of the barge deck in a light condition, all devices were expected to achieve a firing range of at least 200 meters during the test. Barge distance from the ETV was measured using a laser range finder so that an approximate projectile range could be recorded. Based on each device's average distance fired, a range score was assigned between 1 and 5. A score of 5 represents a device that achieved an average range within 80% to 100% of the stated maximum range or greater. A score of 4 represents the next highest 20% (60-80%), and so on until a score of 1 corresponding to a device achieving less than 20% of the maximum range. A device with an average firing distance over and beyond the barge received a 5.

Accuracy and Wind Deflection

Emergency towing scenarios can occur in a variety of weather conditions, which makes projectile wind deflection a serious concern. Lack of accuracy due to wind conditions could lead to longer rescue evolutions as rescue crews attempt to establish a messenger line connection. For this reason, devices were tested in both downwind and crosswind orientations. During crosswind tests, projectile deflection was observed as an angle measured from the intended firing line. Scores were assigned between 1 and 3. A score of 1 indicates significant deflection (>10°) in crosswinds, and a score of 3 indicates very little or no deflection (<5°) in crosswinds.

Range Uniformity

For nearshore rescues, where collision or grounding are threats to a vessel, time is of the essence in attempting to take a ship in tow, therefore the ability to quickly hit the target ship with the line throwing device is of the utmost importance. In addition to the overall range of each projectile, the difference in range between multiple tests was evaluated to better understand the uniformity between shots. A score between 1 and 3 was assigned based on the spread of distances each line achieved. Distance spread was analyzed based on the scores given for the *Range* criterion, as described above. The point spread was defined as the difference between the highest and lowest

Range scores achieved by a device in each testing scenario. A spread of two points or more resulted in a score of 1, a spread of one point resulted in a score of 2, and a spread less than a point resulted in a score of 3.

Ease of Reload

Another aspect of reliability that was evaluated is the time and effort it takes to reload the device and queue up a repeat shot/attempt. If the first shot from a device misses the target vessel, the time it takes to set up for another attempt should be minimal. For this reason, the time required to ready each device for repeat shots and the ease of reload was recorded. The devices received a score based on these two metrics between 1 and 3. A device received a 3 if it could be easily prepped for a repeat shot with minimal effort within 2 minutes. A reload time between 2 and 3 minutes achieved a score of 2. A score of 1 was indicative of a device that took more than 3 minutes or a considerable amount of effort to reload between shots.

Firing Control Safety

Safety is a critical aspect for evaluating best available technology. It is impacted by projectile type, propellant type, and device design. For practical trials, safety was assessed in terms of an operator's ability to safely control each device while firing it. Operators gave a score from 1 to 3 to each device based on their perception of how safe the device was to manage during firing, with a score of 3 representing a device that is easy/safe to control and a score of 1 representing a device that is difficult/unsafe to control. A list of anticipated risks and their likelihoods was developed for each device. The practical firing control score was combined with the risk consequence matrix to provide an overall safety rating for each device. The risk consequence matrix developed is shown in Appendix B.

Device Build Quality

It is critical to the success of a towline deployment that an operator can reliably fire the device, often multiple times. A deployment which results in a damaged firing device or projectile can result in difficulty aiming accurately, reduced projectile flight performance, or even inability to continue device use. For this reason, the construction quality and robustness of each device was evaluated after the full series of deployments. Each device was given a binary pass/fail score based on its ability to reliably fire each projectile without firing failure or impact on performance. Failure of projectiles to fire or device damage from ordinary usage resulted in a failure.

Line Deflection from Projectile Path

Ideally a device deployment will result in a projectile arc that crosses the disabled vessel so that the line/cordage trailing the projectile falls to the deck where it can be retrieved. In crosswinds, however, the trailing line, or "shot line," can become "caught in the wind" resulting in a significant downwind deflection, even when the projectile's path is minimally affected. It is possible, especially when firing long range devices over short distances or at small targets, for the trailing line to deflect downwind around the target, even if the projectile follows an arc directly over it. Multiple shots during the trial resulted in lines that deflected around the barge in a crosswind. Each device's maximum line deflection away from the projectile was examined to evaluate the distance between the projectile path and the deviation of the line in wind. A device passed this criterion if its average line deviation maximum was less than 30 meters.

Test Criteria Evaluated – Surface Float Line

Behavior of Deployed Surface Line

The effectiveness of a surface float line is greatly affected by the behavior of the line once released from the disabled vessel. Ideally the line will stream out in a straight upwind and/or downcurrent direction from the disabled vessel to allow a responding vessel to retrieve the line without having to make a close approach. The behavior of the surface float line was observed as downwind drift of the disabled vessel, simulated through barge maneuvering by the Control Tug. Drift simulation was accomplished by walking the barge downwind between 1 and 2 knots, which allowed the surface line to properly deploy.

Ease of Retrieval

The most difficult aspect of a float line scenario for a rescuing vessel is the retrieval of the line from the water. Difficulty picking up the line can result in increased rescue times and increasingly complex scenarios for the responding vessel as the disabled vessel continues to drift in the water. Additionally, an unsecured line floating near a tug's stern poses the risk of becoming entangled with a propeller. Retrieval of the line was attempted with the PLT-Multi grapple attachment, with a pike pole on standby in the event of a miss.

Time to Complete Retrieval Scenario

The previous best available technology study identified surface float line systems as being well suited to heavy weather scenarios because of their unique ability to quickly deploy and establish a connection without need for an intermediate lightweight messenger line. To verify that such a system could be deployed as rapidly as expected, the time to complete a deployment scenario was evaluated. The time required to establish an emergency towing connection is a criterion that should ideally be minimized, as a disabled vessel poses risk to its crew, the cargo on board, and the surrounding environment. From the time the float line was deployed from the barge, the time required to complete line retrieval, establish a connection, and begin towing the vessel was recorded to understand total elapsed time.

Test Scoring and Rubric

Score	Ease of Use		Effectiveness		Reliability		Safety	Added Criteria	
	Ergonomics	**Weight**	**Range**	**Accuracy and Wind Deflection**	**Range Uniformity**	**Ease of Reload**	**Firing Control**	**Build Quality**	**Line Deflection**
1	Form negatively impacts aiming or firing ability	Mass negatively impacts aiming or firing ability	Device achieved an average of 0-20% maximum range	Significant wind deflection, >10°	*Range* score spread ≥2	Considerable time/effort required to reload	Difficult to control while firing/ unsafe	Build quality impacts firing	Significant deviation from rocket arc, >30 m
2	Form has no significant positive or negative effect on operation	Mass has no significant positive or negative effect on operation	Device achieved an average of 20-40% maximum range	Moderate wind deflection, 5-10°	*Range* score spread 1	Moderate time/effort required to reload	Moderate effort to control while firing	Quality of device is reliable and secure	No/ minimum deviation from rocket arc, <30 m
3	Form positively impacts aiming or firing ability	Mass positively impacts aiming or firing ability	Device achieved an average of 40-60% maximum range	Little/no wind deflection, <5°	*No Range* score spread	Little time/effort required to reload	Easy to control while firing/safe design		
4			Device achieved an average of 60-80% max range						
5			Device achieved an average of 80-100% max range						
Weighting	1	1	3	3	2	2	2	1	1

Test Procedure

The test procedures followed on the day of the trial:

1. Line Throwing Device Downwind Testing
    a. Maneuvered by the Control Tug, the barge was positioned 200 meters downwind of ETV.
    b. The distance to the barge, wind speed, and the inclination angle of Device 1 were measured and recorded.
    c. Device 1 was fired across the mid-body of the barge from the ETV.
        i. *Ease of Use*, *Range,* and *Safety* criteria were recorded.
    d. Device 1 was reloaded.
        i. *Ease of Reload* criteria were assessed and recorded.
    e. Steps b through d were repeated twice with a new test engineer for Device 1 for a total of 3 shots.
        i. *Range Uniformity* data were recorded.
    f. All Downwind Testing steps were repeated for the remaining devices.
2. Line Throwing Device Crosswind Testing
    a. Maneuvered by the Control Tug, the barge was positioned in a crosswind orientation 200 meters from the ETV.
    b. The distance to the barge, wind speed, and the inclination angle of Device 1 were measured and recorded.
    c. Device 1 was fired across the mid-body of the barge from the ETV.
        i. *Ease of Use*, *Accuracy and Wind Deflection,* and *Safety* criteria were recorded.
    d. Device 1 was reloaded.
        i. *Ease of Reload* criteria were assessed and recorded.
    e. Steps b through d were repeated twice with a new test engineer for Device 1 for a total of 3 shots.
        i. *Range Uniformity* data were recorded.
    f. All Crosswind Testing steps were repeated for the remaining devices.
3. Line Throwing Device Simultaneous Firing
    a. The distance to the barge and the wind speed were measured and recorded.
    b. All devices were fired simultaneously from the ETV.
        i. Video footage was analyzed post-test to evaluate wind deflection and range.
4. Surface Float Line System Testing
    a. A positively buoyant synthetic line with the EVATS retrieving line system attached to the distal end was deployed from the barge to simulate an emergency towing hawser. At the proximal (barge) end, the line was attached to a bitt for towing.
    b. Barge drift was simulated by the Control Tug, which walked the barge sideways to mimic a disabled vessel laying in the trough, perpendicular to wave heading. The Control Tug made use of natural environmental forces to augment the drift state and provide more realistic motion.
    c. The ETV attempted to recover the retrieving line with the PLT-Multi grapple projectile, haul aboard the synthetic line, and shackle the eye-splice of the hawser directly to the end of the tow wire. A pike pole was used to retrieve the line after the PLT-Multi failed to successfully grapple the line.
        i. Line behavior and ease of retrieval and time elapsed data were recorded.

d. The ETV commenced towing procedures and began a mock tow of the barge.

Analysis Methodology

As each deployment occurred, wind speed, distance to the barge, device inclination angle, and operator comments were recorded. After aerial video footage was received, distances and angles were evaluated to generate scores based on the scoring matrix. Figure 2 provides an example of an aerial video still after analysis markup. Here, the attitude of the trailing line at the time of projectile touchdown is outlined in blue and the distances to the touchdown point and the midpoint of the barge are drawn in green.

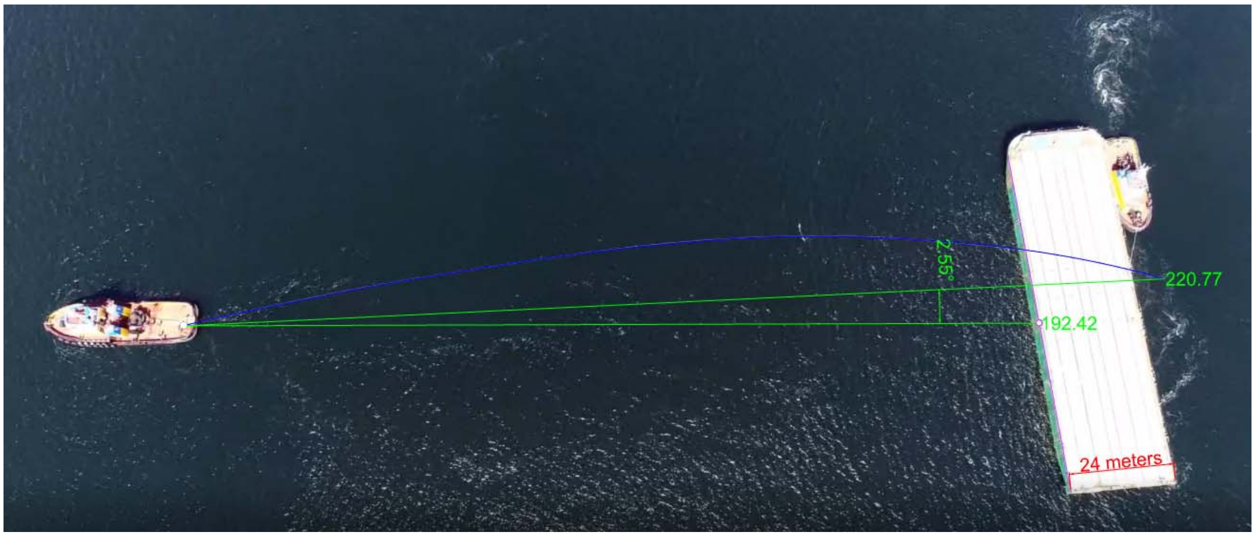

Figure 2 Crosswind deployment analysis markup

To assess the maximum deviation of the shot line from the projectile path, a curve deviation function was run. An example of the outcome of this is shown in Figure 3.

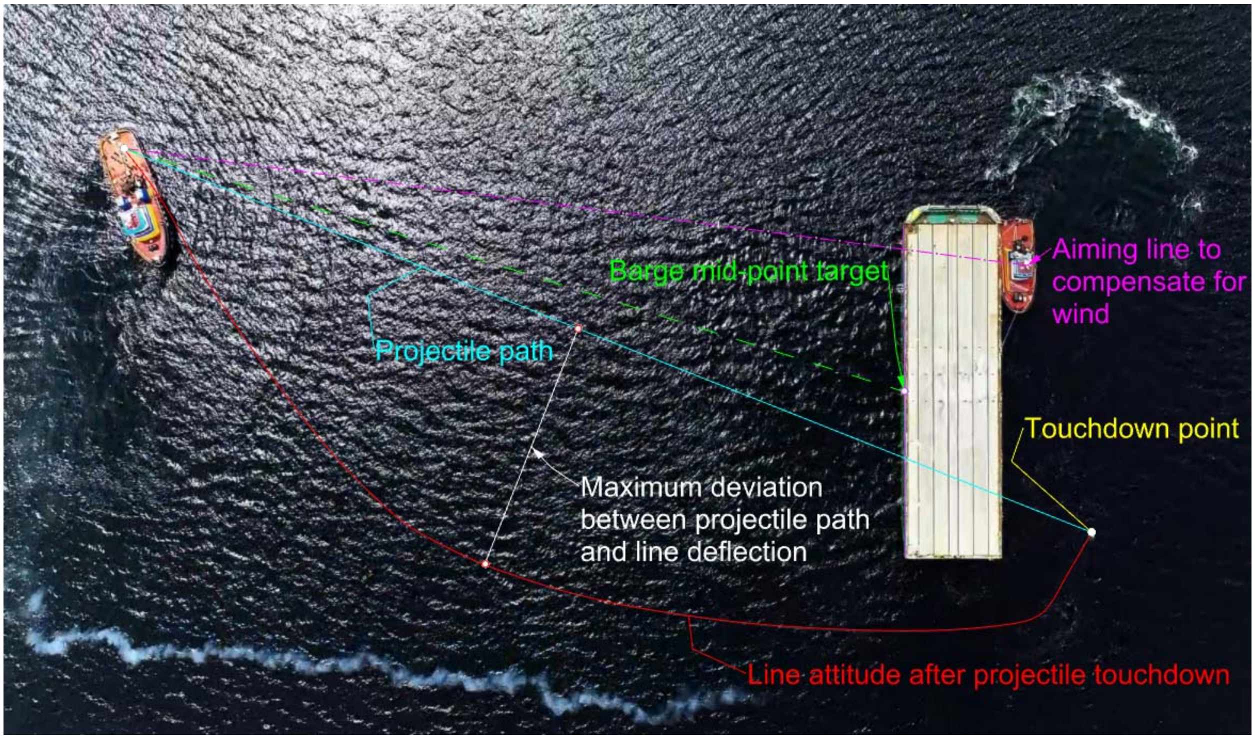

Figure 3 Example of maximum shot line deflection analysis

The average distance to the barge for each device was between 193 and 212 meters for all testing. The average wind speed for downwind tests was between 11 and 13 knots, and the average wind speed for crosswind tests was between 16 and 19 knots for each device.

To ensure that differences in environmental conditions between shots did not skew the results of the testing, a comparison was made between wind speed and projectile angle, meaning the angle between the mid-point of the barge and the projectile's actual trajectory. Figure 4 shows the wind speed against the projectile deflection angle for all the crosswind tests. The projectile deflection angle refers to the angle between the projectile's intended target, the barge mid-body, and its actual touchdown point. There is no clear correlation between higher wind speeds and larger deflection angles between the tests. This may have been caused by fluctuations in wind speed mid-flight or by different operators leading the target more to account for increases in wind speed.

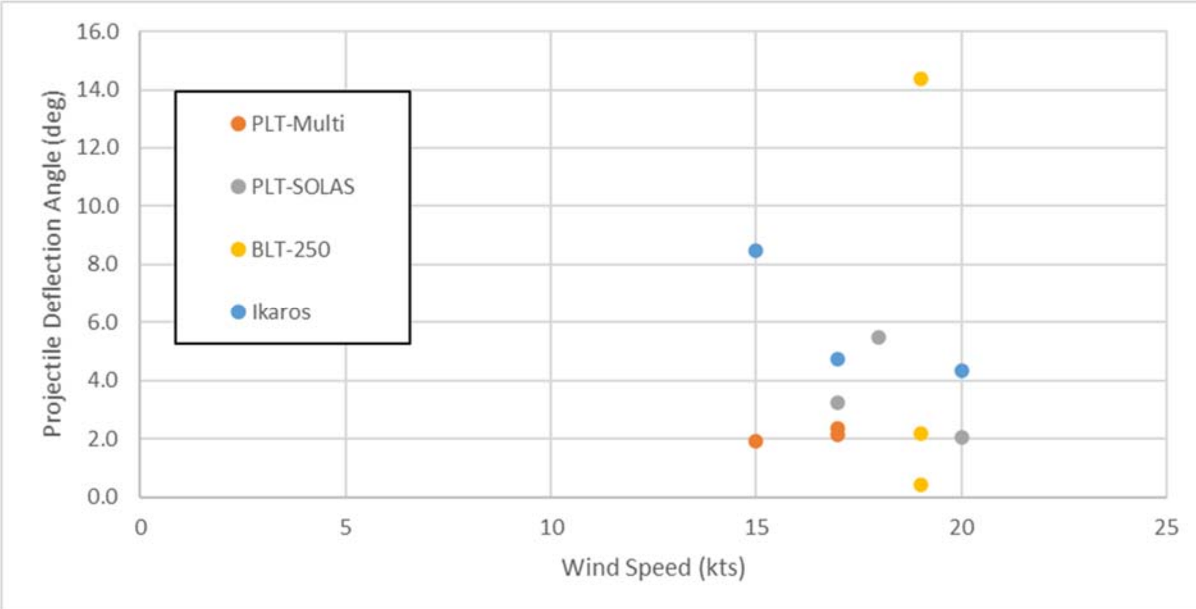

Figure 4 Wind speed to firing angle comparison for crosswind tests

Results

Line Throwing Device Tests

Based on evaluation of the data and analysis of the footage collected during the trial, the results of the scoring matrix are as shown in Table 2 and Table 3 for downwind and crosswind testing, respectively. The overall scores for each device were calculated by summing the score in each category multiplied by its weight.

Table 2 Downwind testing matrix results

	Ergonomics	Weight	Range Score	Accuracy	Range Uniformity	Ease of Reload	Firing Control	Overall
Multi	3	3	5	3	3	3	3	48
SOLAS	3	3	5	2.67	3	3	3	47
BLT-250	3	3	5	3	3	3	3	48
Ikaros	3	3	5	2.33	3	3	3	46
Weight	1	1	3	3	2	2	2	

Table 3 Crosswind testing matrix results

	Ergonomics	Weight	Range Score	Wind Deflection	Range Uniformity	Ease of Reload	Firing Control	Overall
Multi	3	3	4.67	3	2	3	3	45
SOLAS	3	3	5	2.67	3	3	3	47
BLT-250	3	3	4	2.33	1	3	3	39
Ikaros	3	3	5	2.67	3	3	3	47
Weight	1	1	3	3	2	2	2	

The results of the evaluation of the added criteria are shown in Table 4.

Table 4 Added criteria results

Device	Manufacture Quality	Line Deviation from Projectile Path
PLT-Multi	2	2
PLT-SOLAS	2	1
BLT-250	1	2
Ikaros	2	1

Considering the downwind scores, crosswind scores, and the scores for the added criteria, the overall scores out of 100 for each device are captured in Table 5.

Table 5 Overall matrix results for each line throwing device

Device	Overall Score
PLT-Multi	97
PLT-SOLAS	97
BLT-250	90
Ikaros	96

Full results for each device are presented in Appendix A.

Surface Float Line Exercise

The surface float line trial was carried out using a positively buoyant line attached to the EVATS retrieving line assembly. Figure 5 shows the EVATS retrieving line deployed in the water. The line was deployed from a port side bitt off the bow of the barge while the Control Tug walked the barge downwind at approximately 1.5 knots to simulate drift. It took about 6 minutes for the line to unfurl enough for the ETV to position for retrieval. The tug moved into place and the PLT-Multi was deployed, affixed with a grapple hook projectile. The projectile was properly aimed and landed in the water correctly positioned, however was not able to hook the line, instead passing over it. A pike pole was then used to hook the line, haul it aboard, and shackle the hawser to the tow wire on the tug. The total elapsed time between the start of the exercise and the towline coming under tension was 14 minutes and 45 seconds.

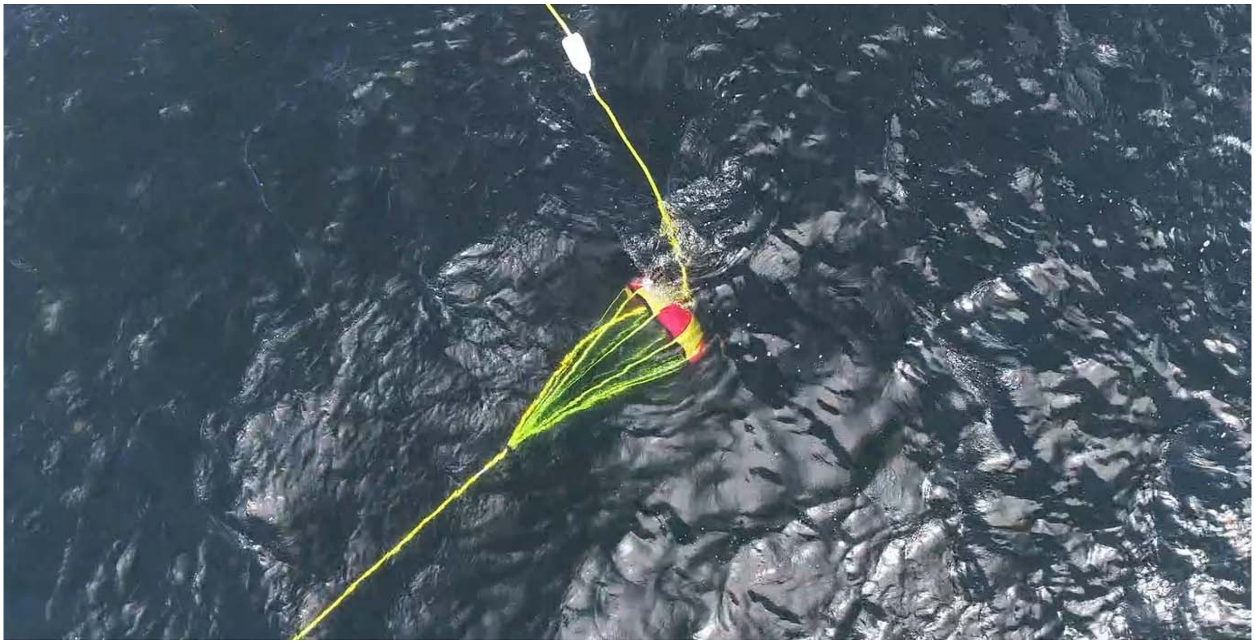

Figure 5 EVATS float line system after deployment

Overall, the float line system behaved as expected, unfurling upwind of the barge such that the ETV could safely move in to retrieve the line. The pilot anchor inflated immediately once pulled by the movement of the drifting barge and the line unfurled completely shortly thereafter. While under tension the anchor dove below the surface, while the two foam floats on the line remained on the surface, visible from the barge and accessible for recovery. The PLT-Multi accurately fired its projectile, though it was noted that the clearance in its hooks would need to be increased, or a smaller diameter line would need to be used to ensure successful recovery.

Discussion of Device Performance

Additional Matrix Criteria

In addition to enabling an objective evaluation of the performance of each device, the trial was highly informative as to the actual operating characteristics of these technologies. Two important takeaways that were apparent from reviewing technical datasheets have already been mentioned: build quality and shot line deflection.

Build quality became a clear criterion to consider only after firing each device. The BLT-250 showed design/manufacturing problems most clearly. The projectiles consistently failed to launch without splitting or fracturing upon activation; and after multiple shots the trigger assembly broke off the body of the device. The Ikaros pyrotechnic device was more reliable; however, it too had one failure related to manufacturing quality. During one of its deployments, the projectile shot line broke away the point where it was "dead ended" on the device and was pulled completely off the deck of the ETV. In a nearshore emergency scenario, losing the line, even after an accurate shot, can result in the loss off critical time.

The line deflection criterion was added to the analysis after observing the crosswind tests. Deployments, even those that accounted for the wind ("leading" the target), resulted in line deflections that were impacted significantly by crosswinds. For multiple deployments, the shot line deflected so much that although the projectile travelled over its intended target, the trailing line was carried downwind to such an extent that it passed completely over the end of the barge and into the water (not retrievable). This represents a shortcoming of long-range devices or those with lines whose windage was larger as they were more prone to catch the wind and be pulled off course. Operators should consider that the smallest amount of deviation in the line is experienced near the touchdown point of the projectile. Therefore, well-aimed deployments at or near the maximum range of a device are most likely to result in a line landing on board the disabled vessel.

One aspect of device design that related to both build quality and line deflection was the quality of the line fitted on each projectile. For example, the Ikaros device was equipped with a 3-strand nylon line that tended to twist as the projectile rotated mid-flight. This resulted in twists at intervals of approximately 30 ft over the length of the line, which increased the windage of the line considerably, resulting in large line deflections during crosswind tests. This effect was further exacerbated by the lack of fins on the incendiary device, which left the projectile without rotational stability in flight.

Commentary on Matrix Scores

For the ergonomics, weight, ease of reload, and firing control categories, all four devices received perfect scores. Though the four devices received equal scores, it should be noted that there were slight differences between them in these categories.

All the devices received top marks on ergonomics and weight, as each of them had been designed with ease of firing in mind. The compressed air devices were heavier than the pyrotechnic device but were fired from the deck, so no points were deducted. The pyrotechnic device, though ergonomic, was considered the most difficult to aim due to its large diameter and firing stance. An operator is required to fire the device with one foot ahead of the other and the device propped against their thigh. Figure 6 shows the Ikaros being fired from the recommended stance.

Figure 6 Ikaros Line Thrower deployment

All devices were reloaded, or replaced, easily within two minutes, so they all received top scores on ease of reload. Being able to pick up a new device like the Ikaros after a failed shot could save a tremendous amount of time but comes with an increased cost over the reloadable compressed air devices.

Finally, each device received a top score on firing control. All the devices felt safe to use and seemed to pose little danger to those firing if they were used properly in accordance with manufacturer guidance. The compressed air devices experienced some slight recoil upon firing and pulled the operator slightly when the projectile caught the target. The pyrotechnic device made use of a multi-stage rocket that generated its own thrust, so the recoil/impact on the user was very small.

The difference in device scores came from the remaining three categories: range, accuracy/wind deflection, and range uniformity.

The range score showed some differences between the devices and highlighted the importance of practicing with each device. For most tests, each device achieved a touchdown distance that was at least 80% of its maximum specified range, at least 200 meters for the pneumatic devices or 240 meters for the pyrotechnic device. Upon not reaching the barge, operators were able to adjust their firing angle to improve the range of the device. Though this may be more difficult to do without a digital inclinometer, it demonstrates the importance of a fast reload to allow for follow up shots with adjustments.

Accuracy and wind deflection were the scoring criterion that revealed the most variation between devices and between conditions. It was assumed that each operator targeted the mid-body of the barge and that any deviation from that was because of the device's inherent inaccuracies or the action of the wind. During downwind tests, device operators aimed directly at the mid-body of the barge, and to accurately target the mid-body during cross wind tests, operators aimed upwind toward the Control tug to compensate for wind action.

Range uniformity was used to assess the reliability of each device and, here again, there were observed differences between the technologies. The Ikaros device, with the longest firing range, was consistently reaching distances greater than 240 meters, 80% of its maximum range. The PLT devices were almost always above 80% of their maximum range, and the PLT-Multi, upon not achieving the required distance on one occasion, was responsive to small changes in inclination angle. The BLT had the most variability in its achieved ranges and for that reason received the lowest range uniformity score.

Comparison to Previous Report

Reference 1 addressed the advantages and disadvantages of several towline deployment technologies from the perspective of their advertised characteristics. Many of the conclusions drawn then have been confirmed by the practical trial. Similarly, some of the considerations that the previous report mentioned must be considered when fully examining the devices tested in the trial.

The previous report recommended the PLT-SOLAS as the top choice towline deployment device and cited several specific advantages. Among the advantages mentioned, the practical trial allowed us to confirm that the high muzzle speed on the projectile does allow for high accuracy and the ability of the projectile to resist wind deflection. In addition, the ability to rapidly fire a new projectile after taking a shot was shown by how quickly the PLT-SOLAS was reloaded and fired again.

The next recommended device was a surface float line system. It was noted that surface float lines could be most well-suited for use in high wind and wave conditions where line throwing devices face the most difficulty hitting their target reliably. The surface float line's effective "range" and its ability to be deployed and recovered quickly were confirmed by how smoothly the surface float line exercise was completed.

The BLT-250 was recommended after the SOLAS and surface line system. Notably, it was given a high rating for its low cost and similarity to the PLT-SOLAS but did not score as highly due to its lower operating pressure and lack of a floating or illuminated line. As shown by the results of this testing, the lower pressure may have resulted in a slightly less reliable firing distance and the lower cost comes with overall lower quality.

Finally, the Ikaros was the next recommended device. Its high effective range was shown clearly by its exceptionally long touchdown distances. The device performed very well in testing with remarkable range and a strong feeling of safety, though the previous report does note some of the disadvantages of working with pyrotechnic devices. The difficulty finding and shipping them, as well as the danger they pose not only to the user but also to the target vessel and the environment, are problems that should not be overlooked when selecting a device. The Ikaros is the only device of those tested that makes use of an active propellant in the projectile - in contrast to the pneumatic devices which use impulse projected projectiles (from compressed air). An active projectile is inherently more dangerous because of its potential to continue discharging propellant after landing, resulting in increased risk to vessel crews, cargoes, and the environment.

Summary and Recommendations

The results of the practical deployment trial demonstrate that the devices identified as best available technology during the previous report are competitive, though there are certainly leading technologies for different scenarios. Additionally, the practical trial provided perspective on the results of the previous study, revealing device characteristics that were not evident from technical specifications/datasheets alone.

The BLT-250 scored well in the previous study, having performance characteristics similar to the PLT-SOLAS. However, upon testing the device practically, its shortcomings in terms of reliability and build quality became evident. Though the device did achieve many of the range and accuracy goals laid out by the test program, its consistent projectile breakages and eventual trigger assembly fracture are problematic for its intended use as an emergency/life-saving device at sea.

The PLT-Multi and PLT-SOLAS are comparable to one another from a capability standpoint. Both devices are highly accurate, well-made, and relatively low-cost, and have the ability to fire not less than four (4) repeat shots before the air cylinder must be replaced or recharged. In the case of the PLT-Multi, there is the added benefit of having multiple interchangeable projectile options, which enhances the usefulness of this device for a range of possible scenarios. Projectile options include: a spherical floating projectile head (useful for small craft recoveries) and a grapple hook projectile head (useful for recovering small diameter lines from the water surface). The passive, non-incendiary projectile on the Restech devices makes them a relatively safe choice for tank vessel operations or situations where crew may be near the landing area of the projectile.

The Ikaros pyrotechnic device clearly offers the best range of the devices tested, however its size and shape make it the most difficult to aim accurately. In a rescue situation, especially one where maneuvering in close proximity may not be feasible, the Ikaros device could provide the additional range necessary to reach an intended target. However, as mentioned previously, because pyrotechnic devices make use of an active incendiary propellant *in* the projectile itself, they carry the risk of igniting flammable or explosive materials/cargoes or injuring crewmembers on deck. The incendiary propellant also leads to difficulties transporting and storing the device. The nature of incendiary devices, generally, makes them a rather inappropriate choice for tank vessel applications.

The surface float line performed as intended, allowing for a safe, effective deployment. In a scenario where line throwing devices cannot feasibly be used, the float line offers a way for a drifting ship to be quickly taken in tow without putting its crew or the crew of a rescuing tug in harm's way. Surface float line systems provide the added benefit of "skipping a step" in establishing the towing connection, as the messenger line is passed directly between vessels with no need for an initial connection with a shot line or other light cordage.

This trial demonstrated that compressed air devices and surface float line systems both provide safe and effective ways for a tug to make initial contact and pass a line to a disabled vessel in an emergency. Surface float line systems may be more consistently usable in foul weather as they offer simplicity in passing a messenger line without need for small diameter cordage. However, they do require deployment from the bow of the disabled vessel. Though pyrotechnic devices offer advantages in range and projectile velocity, for tanker applications, a passive projectile can more safely accomplish this task. Pneumatic line throwers are valuable not only due to their increased safety, but because they allow crews to routinely practice their operation without additional cost or equipment. This routine practice is critical in helping to avoid unprepared operators during an emergency scenario.

Appendix A Line Thrower Deployment Data

Table 6 Line thrower deployment data for downwind and crosswind tests

Condition	Device	Wind [kts]	Barge Distance [m]	Touchdown Distance [m]	Line Angle [deg]	Max Curve Deviation [m]
Downwind	Multi	12	187.9	223.0	2.5	3.0
	Multi	13	192.2	230.7	1.5	2.3
	Multi	13	199.3	233.4	2.0	4.7
	SOLAS	12	192.4	220.8	2.6	13.6
	SOLAS	11	200.2	231.5	0.1	8.6
	SOLAS	12	222.4	238.1	6.6	0.5
	BLT-250	12	193.3	231.6	0.3	9.9
	BLT-250	10	201.1	229.9	1.7	1.6
	BLT-250	11	201.6	238.2	1.4	0.9
	Ikaros	9	200.9	>266.79*	5.3	1.5
	Ikaros	13	200.7	325.4	5.1	0.6
	Ikaros	12	200.2	328.5	1.0	1.5
Crosswind	Multi	15	200.0	196.8	1.9	N/A
	Multi	17	195.3	240.3	2.1	32.6
	Multi	17	209.7	237.2	2.3	27.0
	SOLAS	20	209.8	234.0	2.0	42.0
	SOLAS	18	217.0	234.6	5.5	28.1
	SOLAS	17	211.8	234.5	3.2	42.1
	BLT-250	19	206.3	186.5	2.2	11.2
	BLT-250	19	193.0	232.1	14.4	26.8
	BLT-250	19	202.1	158.9	0.4	1.9
	Ikaros	20	202.3	257.7	4.3	62.8
	Ikaros	17	207.1	295.4	4.7	47.1
	Ikaros	15	195.0	261.8	8.5	58.9

*Projectile range exceeded the field of view of the aerial drone

Appendix B Risk Consequence Matrix

Table 7 Line thrower risk consequence matrix

	Negligible	Marginal	Critical	Catastrophic
Certain				
Likely		Inability to establish ideal downwind firing angle		
Possible	Failure to make contact during initial shot (Far offshore)	Failure to make contact during initial shot (Nearshore)		
Unlikely		Operator injury upon firing or personnel injury on disabled ship (Minor)	Device or projectile damage affecting device usage/ability to fire Personnel injury upon firing or personnel injury on disabled ship (Severe)	
Rare			Premature detonation of incendiary projectile	Ignition of disabled ship cargo Complete failure to make contact with disabled vessel