Cruise Report for 2010 USBL Testing
Strait of Juan de Fuca, Washington

Prepared by: RACE Division Habitat Research Group

Cruise ID:	**FISHPAC**	Vessel(s):	**NOAA Ship *Fairweather***
Cruise Dates:	**June 28 – July 2, 2010**	Project Number:	**OPR-N324**

Alaska Fisheries Science Center
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Seattle, WA 98115-6349

2 November 2010

Overview

The Magnuson-Stevens Fishery Conservation and Management Act requires the National Marine Fisheries Service (NMFS) to characterize and map essential fish habitat and to protect these areas from adverse impacts due to fishing and other activities. The Alaska Fisheries Science Center (AFSC) conducts this research in the Bering Sea, Gulf of Alaska, and Aleutian Islands. NOAA's Office of Coast Survey (OCS) is responsible for providing navigation products and information for transportation safety in these same areas. Since 2006, scientists with the AFSC's FISHPAC project have been working collaboratively with OCS and NOAA Ship *Fairweather* (FA) to integrate the ocean mapping activities of these two organizations in the eastern Bering Sea (EBS). This work involves a variety of towed instruments, including two different side scan sonar systems (Klein 5410, Klein 7180 LRSSS), a towed camera system (TACOS), and an over-the-side grab sampler (SEABOSS). In all cases, a subsurface tracking system is required to provide accurate positioning of the overboard system and the resulting data.

Ultra-short baseline (USBL) systems calculate the subsurface position of an object by combining acoustic range and bearing data from a vessel-mounted transceiver with attitude, heading and location information from the vessel's own navigation system. The object to be tracked needs to be equipped with an acoustic transponder or responder that communicates with the transceiver attached to the vessel. This technology does not require a transponder array to be deployed on the seabed before positioning can commence and is thus ideal for trackline work.

The AFSC purchased a wideband-enabled Sonardyne Fusion USBL system for FA in 2004 in order to provide capability for subsurface positioning of scientific and hydrographic instruments. In 2006, an over-the-side pole was fabricated by a third party using a proven AFSC design, and was successfully used during extended at-sea operations in the EBS. This same pole catastrophically failed shortly after deployment in 2008. The USBL transceiver was subsequently installed in a vacant area of the ship's skeg during FA's 2008-2009 winter-repair period. Performance problems associated with acoustic interference and multipath conditions were identified during sea trials in Puget Sound on 23 April 2009.

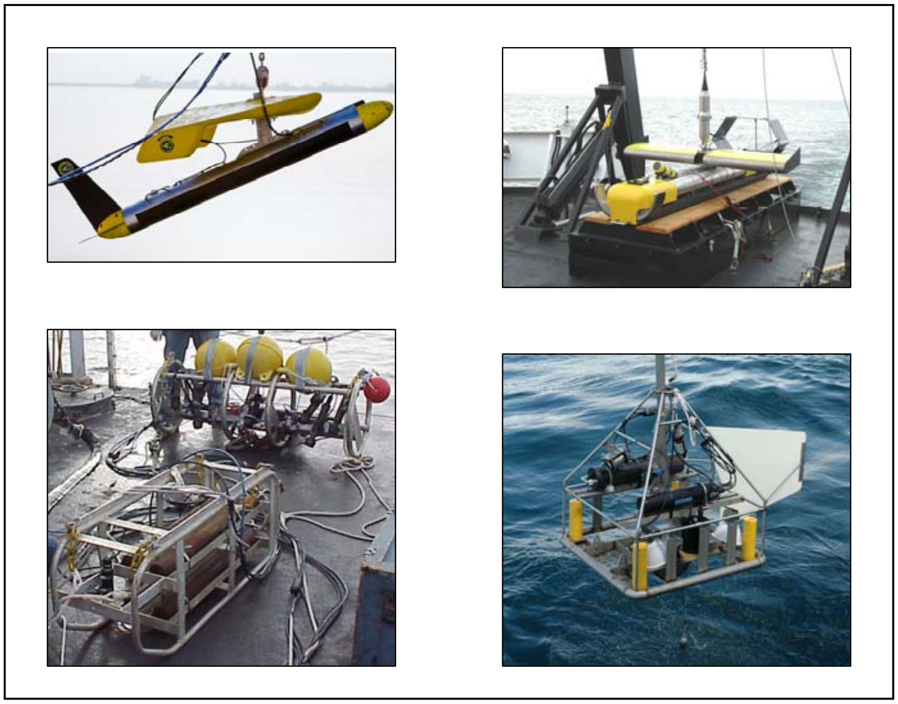

Figure 1. Towed scientific and hydrographic instruments that require subsea positioning capability (clockwise from upper let): Klein 5410 side scan sonar, Klein 7180 long-range side scan sonar, SEABOSS sediment grab/camera system, and the two-part TACOS video sled.

Field operations in 2010 tested performance characteristics of the wideband-enabled Sonardyne Fusion USBL system installed on FA. In particular, various subsea-positioning scenarios were investigated for equipment that is required by the FISHPAC project and future hydrographic surveys (Figure 1).

Objectives

(1) Investigate performance of the skeg-mounted USBL transceiver on FA for subsea positioning of a Klein 5410 side scan sonar at various tow speeds and layback angles.

(2) Investigate performance of the skeg-mounted USBL transceiver on FA for subsea positioning of a Klein 7180 LRSSS at various tow speeds and layback angles.

(3) Investigate performance of the skeg-mounted USBL transceiver on FA for subsea positioning of the TACOS video sled at minimum vessel speed.

Vessels and Gear

Operations were conducted aboard FA, a multi-mission hydrographic survey vessel capable of continuous sonar operations.

The wideband-enabled Sonardyne Fusion USBL system on FA consists of three general components: (1) programmable transponders for the towed instruments, (2) a digital transceiver mounted with 0.2 m clearance from the hull and approximately 5 m forward of the ship's propellers, and (3) a rack-mounted topside system for data processing. Component details and operational settings are presented in Table 1. In general, USBL replies were captured in Ranger software and passed via serial cable to QINSy integrated-navigation software during acquisition. The resulting position data were extracted from the QINSy databases during post-processing.

Table 1. Specifications for the Sonardyne USBL system components. Rx refers to the receive frequency that was used.

Component	Model / Version	Settings
Transponder, wideband directional	8070 WSM	Rx – 32 kHz (Klein 7180) Rx – 33 kHz (Klein 5410)
Transponder, wideband omni-directional	8071 WSM	Rx – 30.5 kHz
Digital transceiver, hemispherical	8021	± 90 degree coverage
Navigation Control Unit	8020	
COMPATT Mk4 transponder with acoustic release and floatation collar	7800 MF	Rx – 31.6 kHz
Calibration software	CASIUS ver. 5.0.1.8	
Acquisition and processing software	Ranger ver. 2.02	

Two different side scan sonar systems and a towed video system were used to evaluate the performance of FA's USBL system. The Klein 5410 is a high-resolution interferometric side scan sonar (455 kHz) and the Klein 7180 LRSSS (180 kHz) is a prototype long-range side scan sonar with an integrated multibeam echosounder and an independent 38 kHz single-beam echosounder incorporated into the towfish. Each towfish was deployed with its respective depressor wing. The third instrument tested was the Towed Auto-Compensating Optical System (TACOS), a two-part towed camera sled that is used to create high-quality downward-looking video mosaics to support interpretation of site-specific seafloor information obtained with the sonars. Subsea positioning of SEABOSS was not included in this exercise because of acceptable performance during the 2009 FISHPAC-project cruise in the EBS. [1]

Itinerary

27 – 29 May	Mobilize AFSC equipment at USCG pier 36, Seattle, Washington.
28 June	Embark FA, Neah Bay, Washington.
29 -30 June	USBL testing aboard FA, Strait of Juan de Fuca, Washington.
1 July	Transit to Manchester fuel depot and USCG pier 36, Seattle, Washington.
2 July	Demobilize and transport all field gear to the AFSC.

[1] *Fairweather* project M-R908, 26 July – 7 August 2009. The cruise report is available at http://www.afsc.noaa.gov/RACE/surveys/cruise_archives/cruises2009/results_Fairweather_FISHPAC-2009-01.pdf

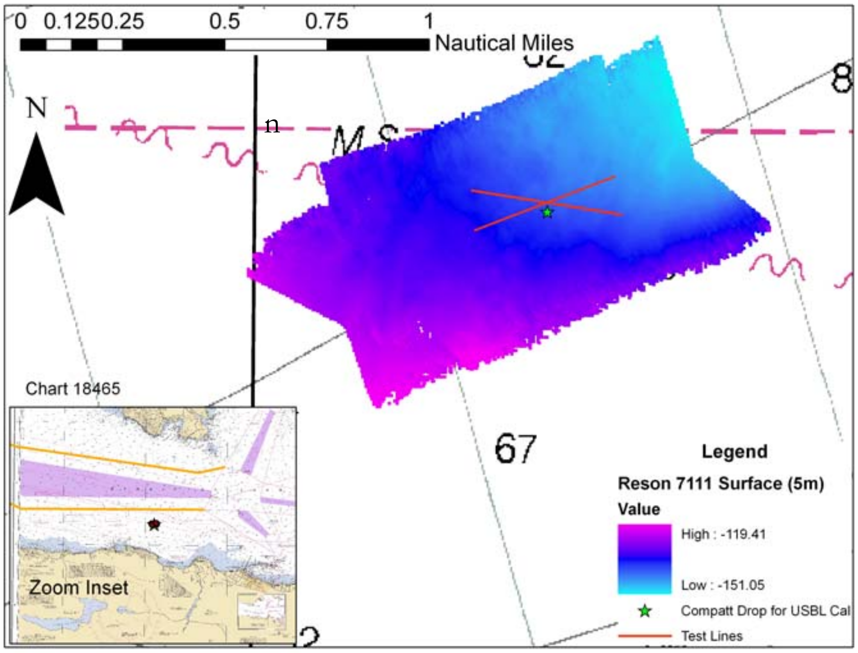

Figure 2. USBL testing area in the Strait of Juan de Fuca.

Study Area

The 2010 study area was located in the Freshwater Bay region of the Strait of Juan de Fuca, Washington (Figure 2). It lay within the eastbound 'recommended two-way traffic' area and was approximately 1 nm south of the main traffic lanes. The seabed in the area was generally flat with depths ranging from 120-150 m.

Methods

A testing program was undertaken to define the performance characteristics of the skeg-mounted USBL transceiver on FA. For each of the three towed instruments, specific combinations of speed over ground (SOG) and bearing from the vessel trackline were tested (Table 2). The range of SOG values, in 2 kt increments for the sonars, covered the standard operating scenarios for acquiring high-quality data with each system. Different layback angles were tested to produce variability in position of the towfish relative to the vessel. This variability routinely occurs when cross currents and winds displace the vessel from the fixed navigation line for the towed device. In practice, layback distance was not a controlled factor and varied as a function of water depth, the amount of cable-out needed to obtain the desired altitude, the position of the depressor wing (fixed for these tests) and the environmental conditions. Layback distance for the TACOS sled was minimal, in keeping with normal practice. USBL testing was originally scheduled to occur during routine hydrographic operations in the Olympic Coast National Marine Sanctuary (OCNMS). However, early completion of that work enabled dedicated maneuvers in more protected waters near Freshwater Bay.

Table 2. Test conditions for evaluating USBL performance. Layback angle refers to instrument position relative to the heading of the vessel, that is, whether it is towing directly behind the vessel (None), is offset to port (OTP) or is offset to starboard (OTS). The USBL system was operated in transponder mode.

Instrument	Altitude	Layback Angle	SOG (kts)	Transponder
Klein 7180	70-120 m [2]	None, OTS, OTP	4 - 10	Directional
TACOS	1 m	Random	1	Omni-directional
Klein 5410	30-80 m	None, OTS, OTP	4 - 10	Omni-directional, Directional

A reconnaissance survey was conducted with the ship's Reson 7111 multibeam echosounder to identify potential hazards in the study area. A dynamic calibration of the USBL system, preceded by a single CTD cast, was completed to determine system offsets and provide accurate positioning capability. Although FA's navigation reference frame was precisely determined during a March 2009 centerline survey by NGS, the USBL reference point remains estimated since the transceiver was installed after the NGS survey was completed. The USBL calibration involved anchoring a COMPATT transponder with a floatation collar and acoustic release in the center of the study area.

[2] Optimum altitude-layback conditions have not been determined for this system. The manufacturer recommends an altitude of 120 m for maximum range, 70-80 m altitude for 100 m water depth (i.e. towfish depth is 20-30 m so as to isolate it from surface effects), and the overall maximum altitude is 200 m.

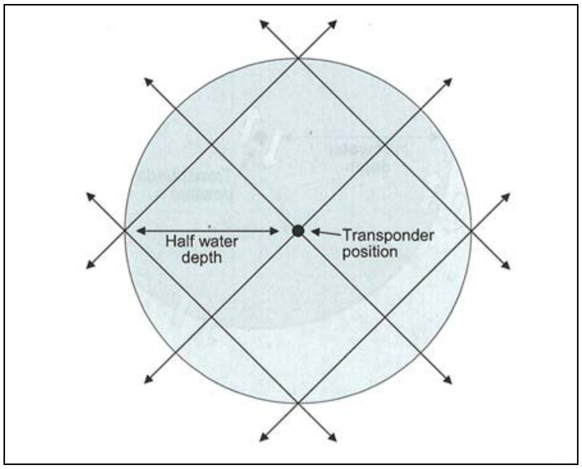

Figure 3. Example of transit lines used to collect USBL calibration data.

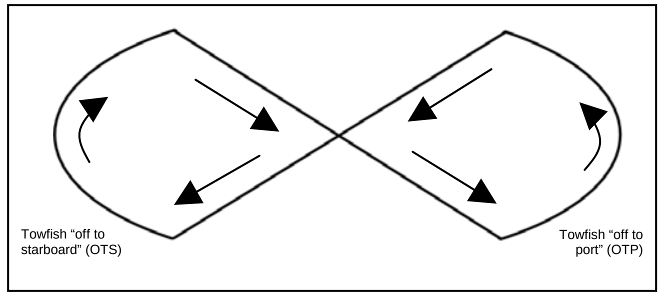

Figure 4. Schematic of the X-shaped maneuvering pattern used to measure USBL system performance while towing a side scan sonar. Straightaway legs of the X were approximately 700 m in length.

This served as the calibration point for a box-in procedure to quantify total system errors between the ship and USBL reference frames. Once deployed, the vessel was navigated in a pattern similar to Figure 3, passing over each of the cardinal points while maintaining a good heading. Twelve calibration lines were run in all – eight transits between adjacent cardinal points in both directions (*i.e.* north-west, west-south, south-east, east-north, north-east, east-south, south-west, and west-north), and two tracklines each crossing over the beacon in both directions. Sonardyne's CASIUS software (Table 1) was then used to determine the calibration corrections for the transceiver installation. Once a satisfactory solution was obtained, the acoustic release was activated and the COMPATT unit floated to the surface for recovery.

USBL performance while towing the side scan sonar systems was measured on a fixed X-shaped maneuvering pattern (Figure 2, Figure 4) where the test conditions for each pass varied according to the predetermined plan for each instrument (Table 2). A complete circuit of the X and the two accompanying turns was completed at each test speed. The maneuvering pattern was continuously navigated with a particular towfish until testing with that system was completed. The first run of each set began with the vessel drifting and the towfish hanging at the prescribed altitude. Vessel speed was then slowly increased to 4 kts enabling system-performance measurements as a function of towfish angle from the water surface. Vessel speed was raised to the next test speed when lined-up for the next circuit around the pattern. The arms of the X were defined by fixed points with unspecified turning arcs at each end. This provided positioning information with the towfish tracking astern and when offset to port and starboard (as frequently happens when navigating a towfish rather than the vessel along a trackline). Cable-out was usually reduced during turns to maintain a safe altitude and was subsequently paid-out during the approach to the next line. USBL performance while towing TACOS was measured in the same maneuvering area but did not include turns because of reduced steerage at minimal headway. In general, at least 5 min. of data were collected for each test using Sonardyne Ranger software (Table 1). Shaft RPM and propeller pitch corresponding to each set of test conditions were recorded by the vessel operators whenever changes were made.

Early completion of the original test plan allowed supplemental testing with the Klein 5410 towfish. In particular, the omni-directional transponder was replaced with a directional unit (Table 2) and USBL performance was measured along an extended straightaway at speeds ranging from 0 (with towfish hanging in the water column) to 10 kts SOG.

Three methods were used to evaluate USBL signal quality and overall system performance. The first method applied quality flags stored in the Ranger software to determine the percentage of transmitted signals that resulted in good navigational fixes. In this case, a code 3 indicated an acceptable response whereas codes 0 (poor quality overall), 1 (bearing rejected) and 2 (range rejected) were deemed unacceptable. The second method used post-processed data to determine the percentage of the total trackline length for which there was usable data. For this analysis, navigation data were extracted from QINSy and smoothed using a general time domain filter (*i.e.* filter 1d in Generic Mapping Tools open-source software[3]). Smoothed navigation data for each of the towed systems were imported into ArcGIS software where the track lines for each test speed were then manually split to assemble data for the three layback-angle scenarios. Finally, the plotted

[3] See http://gmt.soest.hawaii.edu/

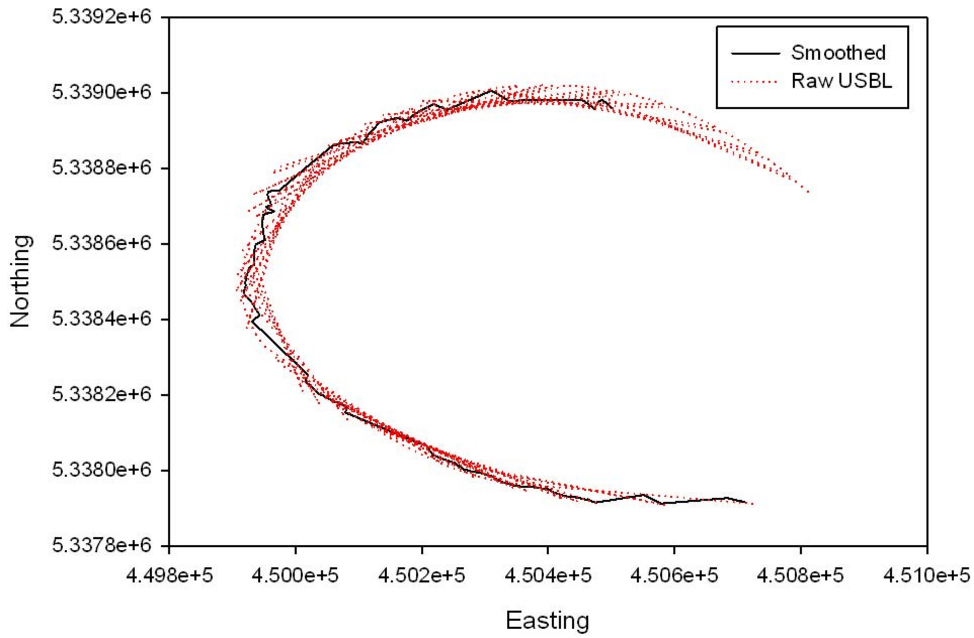

Figure 5. Smoothed (black) and raw (red) USBL data for an 8 knot tow with the Klein 7180 towed OTS of the vessel (directional beacon). The erratic responses throughout the track are not usable for side scan image processing.

fixes were examined to subjectively determine the amount of usable data. For example, Figure 5 shows smoothed and raw USBL output from a trackline segment where the majority of fixes were of poor quality and unusable even after smoothing. Finally, survey log files in Ranger were examined to assess the effects of propeller pitch and engine RPM on signal quality.

Results

Scientific equipment was installed in Seattle on 27-29 May prior to FA's departure for the working grounds. USBL testing occurred 29-30 June and FA returned to Seattle on the evening of 1 July. The cruise plan was fully executed and some additional testing was also accomplished.

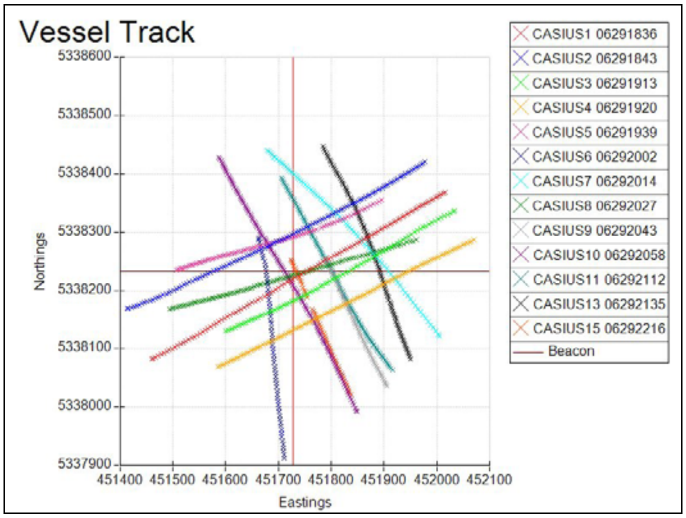

Figure 6. Orthogonal grid of tracklines centered on the moored COMPATT beacon. Compare with plan in Figure 3.

The preliminary reconnaissance survey was completed using the ship's Reson 7111 shallow-water multibeam echosounder. Full-coverage bathymetry and backscatter data were collected in the testing area (Figure 2). After minimal processing, a review of the data indicated a generally featureless bottom free of potential hazards for the towed instruments.

Calibration

The USBL system was calibrated with systematic data collected over the course of 3.5 hours (Figure 6). This was the first attempt to calibrate the skeg-mounted transceiver on FA. Approximately 6 hours were required for the full evolution, involving a CTD cast, deploying the COMPATT transponder, sailing the box-in pattern, calculating the calibration results, and recovering the COMPATT. During much of this time, there was a strong cross-current to the south which caused some difficulty staying on the intended path (Figure 6).

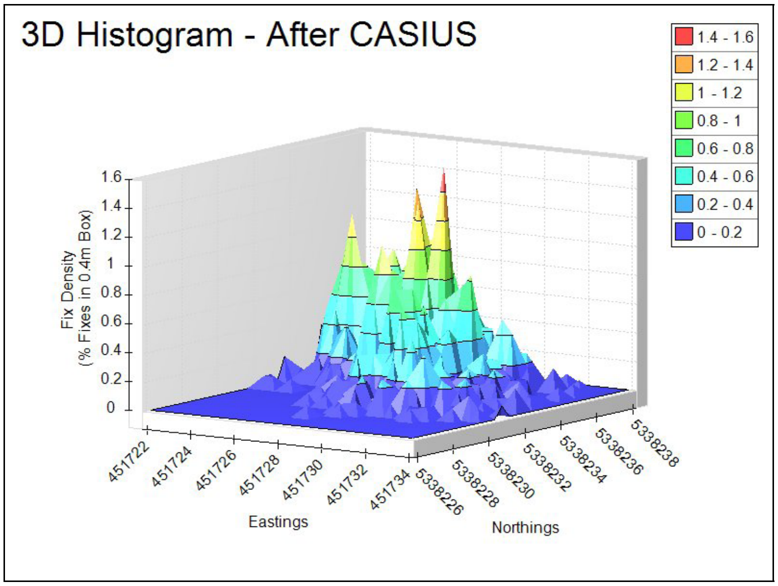

Figure 7. Estimated positions of the moored COMPATT beacon after applying pitch, roll and heading corrections determined with the box-in calibration procedure. Multiple peaks indicate a poor outcome.

A total of 1,210 transponder fixes were collected and used to calculate the installation corrections (Table 3).

Table 3. Installation corrections entered into Ranger software and the corresponding accuracies obtained with the box-in calibration procedure.

Calculated Corrections			Calculated Accuracy		
Pitch	Roll	Heading	Pitch	Roll	Heading
0.32°	0.16°	-0.33°	0.01°	0.02°	0.02°

The data collected during the box-in calibration procedure were also used to estimate the overall system accuracy, but did not produce a high-quality result (Table 4). A good calibration result is indicated by a tight cone of data in the 3D scatter plot whereas multiple peaks were observed in this case (Figure 7). Furthermore, the incidence of depth aiding to arrive at a positioning solution (796 or 66% of all fixes) was marginally acceptable based on manufacturer's guidance that fewer than 70% of fixes should use auxiliary depth-telemetry data. The calibration indicated a 13.64 m discrepancy in the z-offset which, coincidentally, is the lever arm for the POS MV GPS antenna. This discrepancy could explain the inordinately high incidence of depth-aiding.

The two-dimensional accuracy of the system after calibration is usually reported as a percentage of water depth. In general, the uncertainty in position is expressed as the probability that the error will not exceed a certain amount or, equivalently, as the percentage of all fixes that are contained in an error ellipse whose center is the true or correct position of the COMPATT transponder. Sonardyne routinely uses the two-dimensional 1 DRMS (radial or distance root mean squared error) as the preferred measure of accuracy:

$DRMS = \sqrt{\sigma_E^{\,2} + \sigma_N^{\,2}}$, where $\sigma_E^{\,2}$ and $\sigma_N^{\,2}$ are the squared standard deviations (variances) for the Eastings and Northings of the COMPATT fixes.

According to the manufacturer, the ideal spread of fixes with a high-quality position and orientation sensor such as the POS MV should be better than 0.5% of water depth for absolute position whereas the 1 DRMS value was 2.68% of water depth (3.2 m) for this calibration (Table 4). Note that the probabilities are not constant in the two dimensional case but depend on the geometry of the position solution and, as expected, the estimated system accuracy decreases as the statistical confidence in the estimate (i.e. percentage of fixes considered) increases.

Table 4. Two-dimensional estimates of system accuracy based on the box-in calibration and data processing with CASIUS software. CEP is the Circle Error Probable, sometimes referred to as the Circle of Equivalent Probability, which defines the radius of a circle where there is a 50% chance of the position being located. DRMS is the two-dimensional distance root-mean squared error. Sigma refers to the standard deviation of the fixes acquired during the box-in procedure.

Statistic	Probability	System Accuracy (% water depth)
CEP	0.500	2.13
1 DRMS	0.632	2.68
2 sigma	0.865	3.68
2 DRMS	0.982	5.87

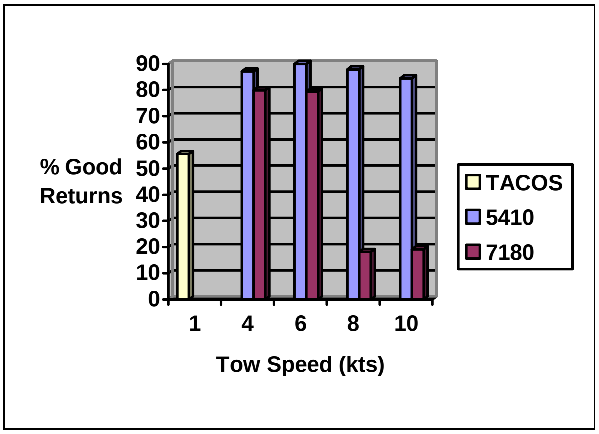

Figure 8. Effect of tow speed on USBL performance.

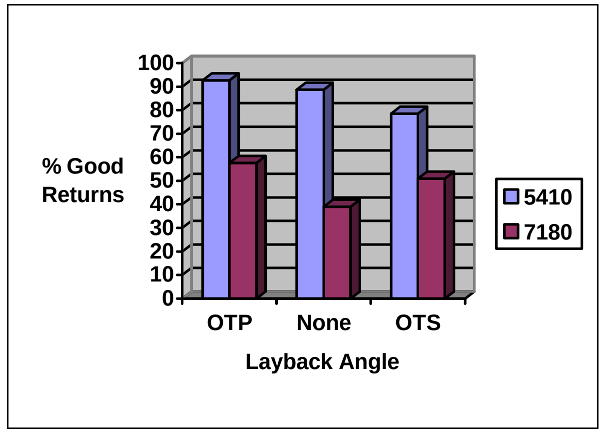

Figure 9. Effect of layback angle on USBL performance.

Performance Testing

Analysis of the quality flags stored in the Ranger software indicated that USBL performance was sensitive to tow speed while being towed around the X-shaped maneuvering pattern (Figure 8; Data Summary section). USBL performance with the Klein 5410 was consistently good with only a modest decline in the percentage of good-quality returns at the higher speeds. Performance with the LRSSS was comparable to this at lower speeds (albeit somewhat reduced) but was substantially degraded while towing at 8 and 10 kts. USBL performance was consistently good as the towfish rose from an initial position dangling near the skeg-mounted transceiver at 0 kts to the final towing position at 4 kts. For both the Klein 5410 and the Klein 7180, USBL performance was best with the towfish tracking to the port side of the vessel track (OTP) and was worst while tracking to the starboard side for the Klein 5410 (OTS) and while directly astern for the Klein 7180 (None; Figure 9). Inherent differences in shape, weight, and acoustic functionality result in markedly different towing characteristics for the two towfish. As compared to the smaller Klein 5410, the LRSSS is navigated at much higher altitudes and requires far less cable being paid out during navigation, regardless of speed (Figure 10). During testing with both Klein instruments, effects of propeller pitch and engine RPM changes on USBL signal quality were not readily apparent in time series plots of acoustic signal level and/or signal-to-noise (Figure 11).

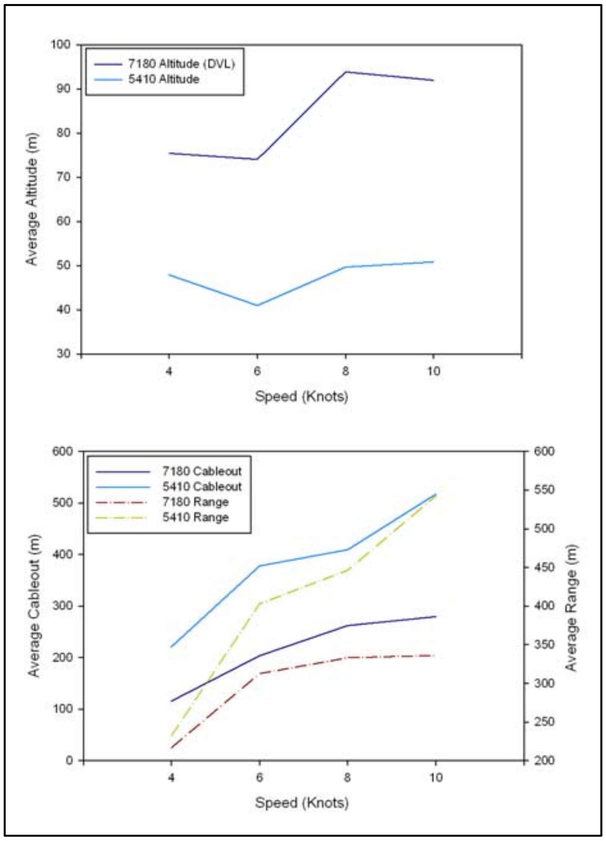

Figure 10. Tow characteristics as a function of speed for towfish tracking directly behind the vessel. Top graph indicates average altitude for each towfish, while bottom graph presents average cable out (solid lines) and average range to beacon (dashed lines).

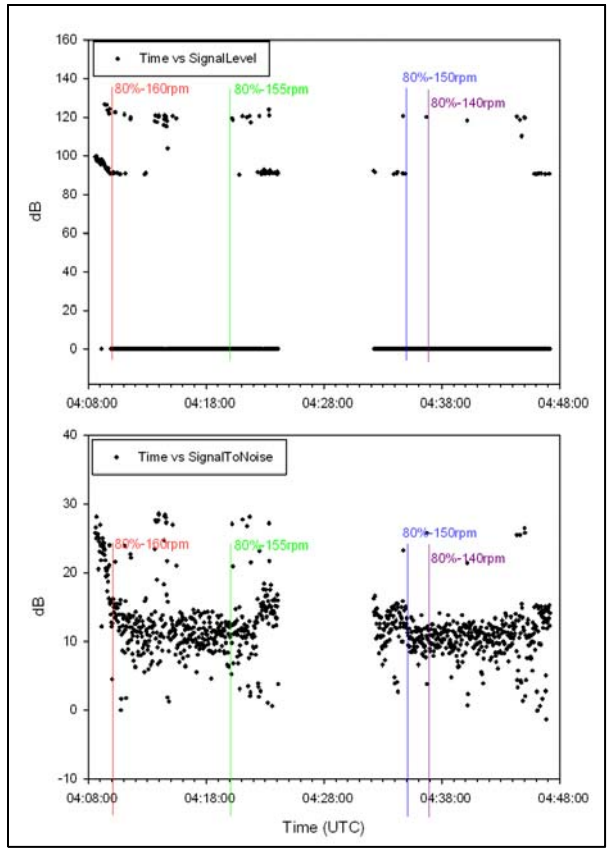

Figure 11. Signal level (top graph) and signal-to-noise ratio (bottom graph) while towing the Klein 7180 at 8 knots using a directional transponder. The four vertical colored lines indicate times when adjustments were made to engine RPM for the given % pitch of the propellers.

Although overall tracking performance with the omni-directional beacon was generally acceptable, interference artifacts in the side scan sonar imagery were consistently observed over a featureless bottom when using the Klein 5410 (Figure 12).

For the TACOS system, a total of 55.6% of acoustic returns were classified as good and usable while being towed at 0.7 kts SOG.

Overall, there was a high correlation between % Good Responses and % Usable Length (r=0.85) so only the former results have been reported here. It is worthwhile to note, however, that it was possible to obtain usable navigation for an entire trackline and thus produce side scan mosaics with as little as 61% of all responses classified as good (code 3).

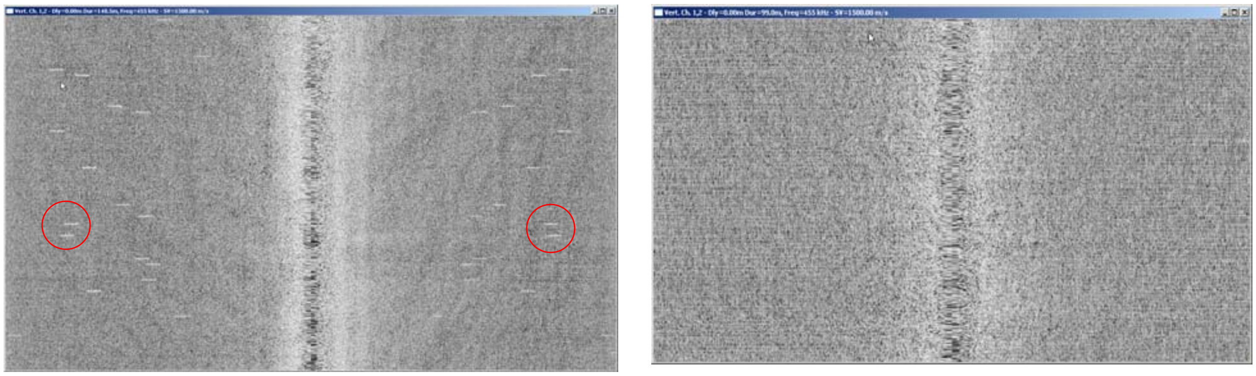

Figure 12. (a) Slant-range corrected side scan imagery acquired at 4 knots with the Klein 5410. Note recurring interference in the left image (type 8071 omni-directional transponder) that is not evident in the right image (type 8070 directional transponder).

Summary & Recommendations

This exercise was designed to test performance characteristics of the skeg-mounted Sonardyne Fusion USBL system installed on FA and to recommend short- and long-term solutions for subsea positioning capabilities. Our results demonstrated inconsistent and therefore unreliable performance from a system that did not calibrate according to manufacturer's standards. Instrument-specific effects on positioning that are related to tow speed and layback angle should be considered deficiencies that limit certain multi-mission research and hydrographic surveying operations from the platform. With the same USBL transceiver installed on an over-the-side pole, a more satisfactory calibration was achieved with the same hardware and software during the 2006 FISHPAC cruise on FA (Table 5). This contrast suggests a problem related to the current installation of the transceiver on the FA's skeg and is consistent with concerns expressed by Sonardyne engineers immediately after the installation that noise and multipath problems were likely based on the particulars of this installation and their collective experience from hundreds of other installations. [4] The manufacturer recommends a minimum 10 m and preferably 20 m separation

[4] Summary of 16 March 2008 e-mail message from Bernard A. Kiddier , Principal Project Engineer with Sonardyne Inc., concerning installation of the 8021 digital transceiver 0.2 m vertical from the hull and approximately 5 m forward of the ship's propellers.

from noise sources. Moreover, they expressed concern about (multi-path) reflections affecting the direct signal path since the face of the transceiver is only 0.2 m (8") from the hull, especially at shallow angles as in towfish tracking. The problem was expected to show up (and did) as either incorrect bearings or cancellation of the direct-path signal or both. This may account for the degraded performance with the Klein 7180 LRSSS which is towed at a substantially greater altitude than the Klein 5410 towfish (Figure 10). In terms of maintenance, the installation is also problematic since the transceiver is permanently fit to the skeg and thus is not accessible without going into dry dock. Furthermore, while total system error less than 3% of water depth at 1 DRMS may be a serviceable level of accuracy for some activities, poor positioning performance with moving targets particularly at higher speeds seriously limits the surveying efficiency of the vessel. Productivity would be further impacted if the Klein 7180 altitude was limited by the USBL coverage envelope since characteristically large altitudes are needed to enable long-range coverage. As noted for the 2009 FISHPAC project, however, the skeg-mounted transceiver will provide acceptable positioning of the SEABOSS device while FA is holding station, and cursory testing in Puget Sound in April 2009 suggests forward-looking positioning of remote objects may also be feasible.

Table 5. Comparison of calibration results obtained for different locations of the USBL transceiver.

Date	Transceiver Location	Fixes Used for Beacon Box-in	% Depth-Aided Fixes for Attitude Corrections	DRMS After Calibration
7/26/2008	Temporary pole (port side)	811	18	1.05% (1.3 m)
6/29/2010	Skeg	1,210	66	2.68% (3.2 m)

In the short-term, the USBL transceiver should be installed on a removable pole mount until such time as directed engineering studies can be undertaken to identify a more permanent solution. In it's present configuration, "the pole may be deployed, in relatively calm seas, at ship speeds up to 15 knots without risk of structural failure" [5], which is completely covers the operating windows for the equipment studied here. Nevertheless, in consideration of the 2008 failure, it would be prudent to incorporate heavier materials and reinforcing into the current design (and to pay close attention to

[5] Conclusion of engineering report by Art Anderson Associates, Bremerton, Washington dated 24 April 2003: "NOAA hydrophone pole for shipboard deployment of USBL transducer - report of pole strength vs deployment speed." Contract No. 50-ABNA-000031.

the quality of materials and workmanship) prior to extended operations in the Bering Sea and the Arctic. Although a pole-mounted system would enable satisfactory subsea positioning, this manner of installation is problematic due to recurring installation costs, the need for a new calibration procedure after each deployment of the pole, frequent loss of the UHMW fairings and difficulty replacing them while at sea, as well as occasional vibrations that are annoying in lower-level ship's quarters. These are, however, relatively minor issues as is the temporary limitation on docking while the pole is deployed. Moving the installation point athwartships to the starboard side of the vessel has never been attempted but would address concerns about interference with rescue boat launch and recovery on the port side.

It may be possible to improve on the overall positioning performance including that attained previously with a pole-mounted transceiver. To this end, it would be worthwhile to use the responder mode of USBL operation whenever possible, so as to minimize through-water communication between the transceiver and the remote transponder. It would also be worthwhile to evaluate using a directional transponder on the Klein 7180, by moving it from the inclined bracket on the towfish to a position on the tow cable near the termination (as is standard practice with the Klein 5410). Finally, it may be advantageous to use a directional transceiver and/or a tilted array adapter to better focus the acoustic energy away from noise sources and more in the direction of the towed instrument. Ultimately, design studies should be undertaken to implement a permanent through-hull installation involving either a hydraulic ram or a moon pool with ready access.[6]

Finally, it should be pointed out that tow winch failures continue to be a serious and predictable vulnerability for operations requiring the capability. During this cruise, problems were encountered involving the hydraulic-fluid level, electrical relays in the winch cabinet, as well as the remote and local joystick controllers. These failures are attributed to infrequent use for conventional hydrographic activities, irregular maintenance, and various design limitations.

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[6] Preliminary design and ABS approval efforts were initiated by the NOAA Office of Marine and Aviation Operations, Electronics Engineering Branch in March 2008.

Data summary

Device	Tow Speed (kts)	Offset	Transponder Type	% Pitch - RPM	% Good Returns
Klein 7180	4	None	Directional	60-135, 30-135	74.9%
		OTP	Directional	35-135, 55-135	78.6%
		OTS	Directional	60-135, 30-135	86.1%
	6	None	Directional	(80-150), 60-140, 65-140, 70-140	65.3%
		OTP	Directional	70-140, 80-140, 50-140	98.4%
		OTS	Directional	65-140	74.5%
	8	None	Directional	(55-135), 80-160, 80-155, 80-150, 80-140	10.3%
		OTP	Directional	80-140, 80-150	30.3%
		OTS	Directional	80-155	13.9%
	10	None	Directional	(50-140), 85-160, 90-165, 90-175, 90-185	5.5%
		OTP	Directional	90-185, 75-185	22.8%
		OTS	Directional	85-160, 90-165, 90-175	29.2%
Klein 5410	4	None	Omni-directional	65-130, 45-130, 30-130	93.1%
		OTP	Omni-directional	30-130, 40-130, 45-130, 60-130, 70-130, 55-130	97.3%
		OTS	Omni-directional	(65-130), 45-130, 30-130, 25-130, 35-130	91.1%
	6	None	Omni-directional	(75-150), 84-150; 40-132	97.0%
		OTP	Omni-directional	50-140, 70-140, 80-150	88.4%
		OTS	Omni-directional	84-150, 50-140, 40-140	84.9%
	8	None	Omni-directional	85-170; 60-150	98.2%
		OTP	Omni-directional	80-150, 85-170	95.9%
		OTS	Omni-directional	85-170, 70-160, 60-150	60.9%
	10	None	Omni-directional	(75-170), 90-185; 80-170	92.7%
		OTP	Omni-directional	75-170	83.3%
		OTS	Omni-directional	90-185, 80-170	77.4%
TACOS	1	Random	Omni-directional	no data	55.6%
Klein 5410	4	None	Directional	no data	67.1%
	6	None	Directional		82.2%
		OTP	Directional		97.5%
	8	None	Directional		91.0%
		OTP	Directional		93.6%

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