Recommendations for Reporting Vessel Geometry and Multibeam Echosounder System Offsets

Multibeam Advisory Committee

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Purpose

Vessel survey reports (VSRs) play a critical role throughout service life (10+ years) of a multibeam echosounder system (MBES) and provide the foundation for future vessel and sensor surveys. This document provides recommendations for VSRs that minimize opportunity for errors in the configuration of MBES and ancillary sensors.

Introduction

The quality of MBES data depends on the performance and integration of several components in the system (e.g., antennas, motion sensors, and transducer arrays). These sensors are configured in their respective software packages using linear and angular offsets measured by a third-party surveyor and documented in a VSR. The VSR provides the foundation for mapping system configuration and all future vessel surveys, such as those required after the addition or relocation of sensors.

The absolute dependence of MBES configuration on the VSR cannot be overstated. Unclear or ambiguous presentation of the vessel survey results can lead to erroneous sensor configuration and difficulty in re-establishing the vessel reference frame during future vessel surveys. Errors in MBES configuration can manifest in many different forms, such as difficulty during calibration or depth artifacts across the swath correlated with vessel motion. These errors often persist for many years due to the infrequency of opportunities to survey a vessel (especially dry dock opportunities to survey transducer arrays). Sensor offsets are applied in real-time by the position, attitude, and acoustic systems (e.g., beamforming during transmission and reception, Doppler correction for vessel attitude velocities during bottom detection). Errors in these offsets propagate through to the bathymetry data, and often cannot be corrected after acquisition.

Considering the significant costs of MBES installations, ship time for data acquisition, and data processing at sea and ashore (as well as the wide variety of end-users for the bathymetry products), there are significant incentives to ensure a high-quality VSR and its correct translation into MBES configuration. This document recommends reporting practices for the most important MBES elements based on Multibeam Advisory Committee review of a wide variety of reports since 2010. It is intended for reference by ship operators and surveyors throughout planning, surveying, and reporting to improve the translation from VSR to MBES setup.

Critical Components of Useful Survey Reports

MBES configuration is streamlined - and opportunities for error are reduced - when the VSR clearly presents and demonstrates the following:

1. **Origin** of survey reference frame
2. **Axes** of survey reference frame
3. **Sign conventions** of survey results
4. **Images** of surveyed points and sensors
5. **Sigma** / standard deviation or uncertainty of survey results
6. **Second review** before submission

In addition to these elements, the VSR should include a simplified table of results that can be applied directly to MBES configuration; an example table is included below.

1. Origin of the survey reference frame

a. The origin of the survey reference frame should be a permanent, physical location on the hull or other fixed location. Many vessels employ an etched plate specifically designated as the origin of the vessel reference frame. It must be accessible for follow-up surveys and absolutely unambiguous; ideally, for ease of reference, the origin is not ‘in air’ or underwater.

b. The origin can be co-located with that of the MBES reference frame at a specific sensor, such as a manufacturer-designated survey target on a motion sensor housing.

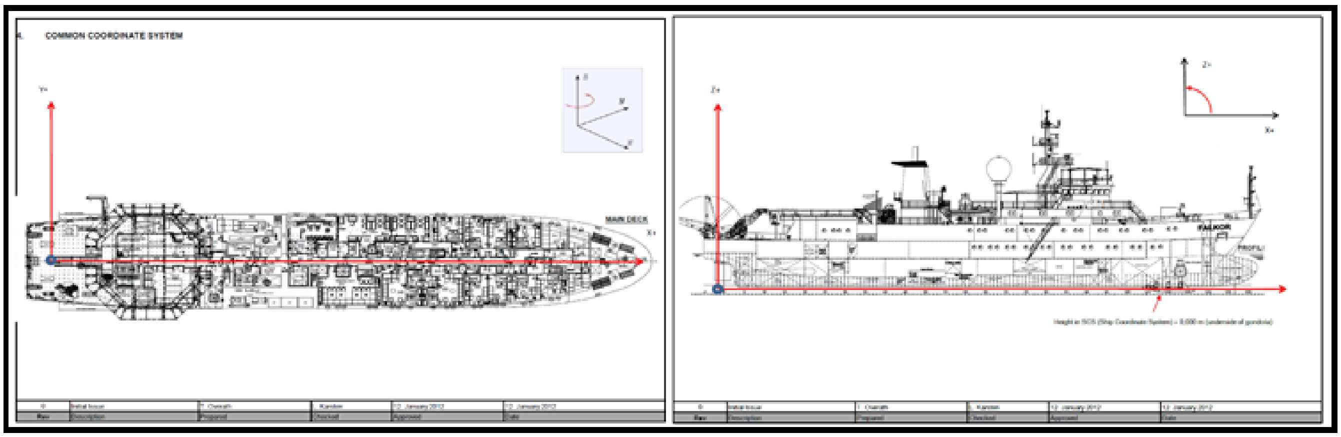

Figure 1. This survey origin is logically based on major hull features and clearly documented. However, the origin is not physically located on the hull, making it less intuitive for the wide audience of survey report readers. The origin is a point in air (or water) based on centerline at the keel height near the stern; depending on the accessibility of other benchmarks, this survey origin may complicate re-establishing the vessel frame outside of dry dock. (Images: Fugro)

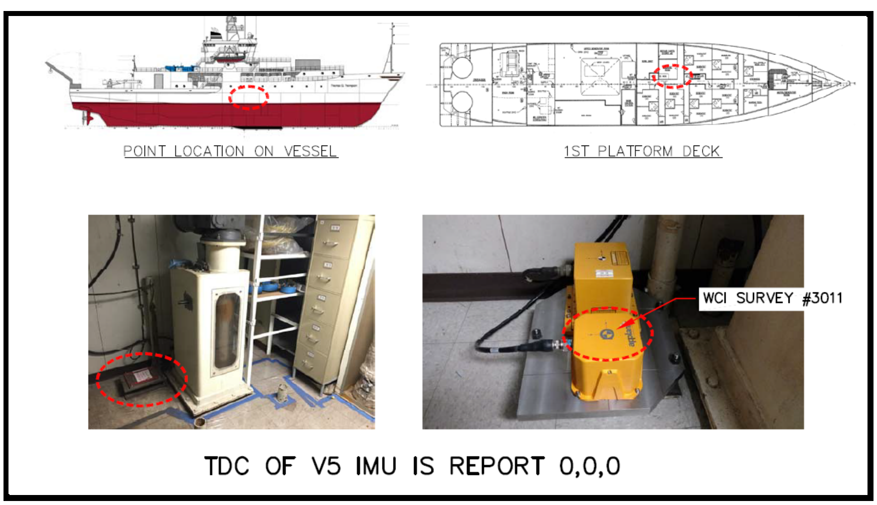

Figure 2. The most useful and intuitive origins described in survey reports are unambiguous, durable, physical markers that are accessible at any time. This example survey origin is a clear, permanent target on the motion sensor housing that is conveniently co-located with the origin chosen for mapping system configuration. (Image: Westlake Consultants, Inc.)

2. Axes of the survey reference frame

a. The survey report must clearly describe the three major axes (alongship, athwartship, and vertical) using common axis labels (e.g., X, Y, and Z).

b. If the survey is conducted in a reference frame that is not aligned with the major axes of the hull, the final report must transform the results into a vessel-based reference frame. Linear offsets must be clearly reported using these major alongship, athwartship, and vertical axes.

c. Likewise, regardless of the reference frame(s) used for survey calculations, all angular offsets must be clearly reported as rotations about these major alongship, athwartship, and vertical axes.

d. The survey results must be reported in one consistent reference frame.

e. See #3 below for additional notes on sign conventions.

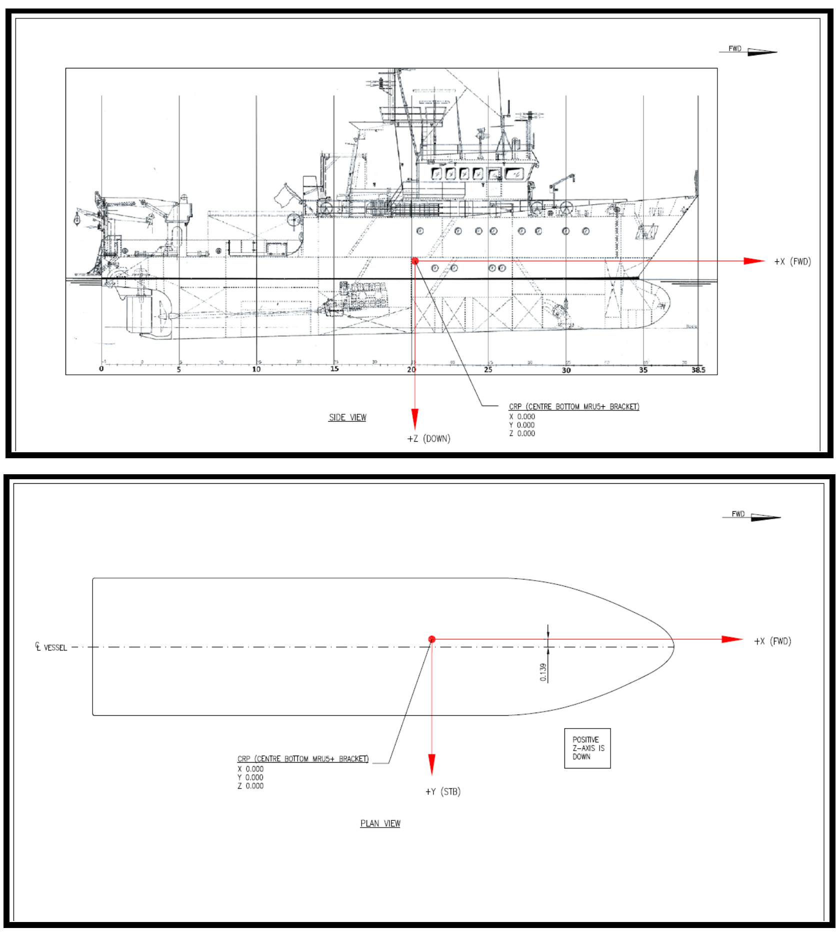

Figure 3. The major coordinate axes and origin are clearly presented for this vessel survey. (Images: Parker Maritime)

3. Sign conventions of the survey reference frame

a. The sign conventions must be clearly described for the three major positive axes (+X, +Y, and +Z) and the rotations about these axes (+Roll about the alongship axis, +Pitch about the athwartship axis, and +Heading about the vertical axis). All linear and angular offset results must be reported using consistent sign conventions, such as the manufacturer conventions outlined below.

b. Final results for all sensors should be reported using the echosounder manufacturer's sign conventions. Linear and angular sign conventions are described below for the two manufacturers of multibeam echosounder most widely installed throughout the UNOLS fleet:

   i. **Kongsberg** uses a right-handed coordinate system with all rotations following the 'right-hand rule'* about these axes:
      1. X is positive forward
      2. Y is positive to starboard
      3. Z is positive down
      4. Roll (rotation about X) is positive with starboard side down / port side up
      5. Pitch (rotation about Y) is positive with forward side up / aft side down
      6. Heading (rotation about Z) follows the compass convention (positive with rotation of the forward side starboard)
      7. Note: These conventions are also used for the most widely installed positioning systems in the UNOLS fleet (Applanix and Seapath).

   ii. **Reson** uses a right-handed coordinate system with Roll and Pitch (but not Heading) following the 'right-hand rule'* about these axes:
      1. X is positive to starboard
      2. Y is positive forward
      3. Z is positive up
      4. Roll (rotation about Y) is positive with starboard side down / port side up
      5. Pitch (rotation about X) is positive with forward side up / aft side down
      6. Heading (rotation about Z) follows the compass convention (positive with rotation of the forward side starboard)
      7. Note: Reson transducer bracket diagrams may use other conventions locally for the bracket dimensions, but the overall configuration in Reson software uses the convention described here.

c. The sign conventions applied in the survey report must be described clearly in a separate section outside of the results, as well as within each table of results. See the example table at the end.

*The 'right-hand rule' is a common description of rotations about axes. Under this rule, when a right-hand thumb is aligned with a positive linear axis, the curvature of the fingers indicate a positive rotation about that axis.

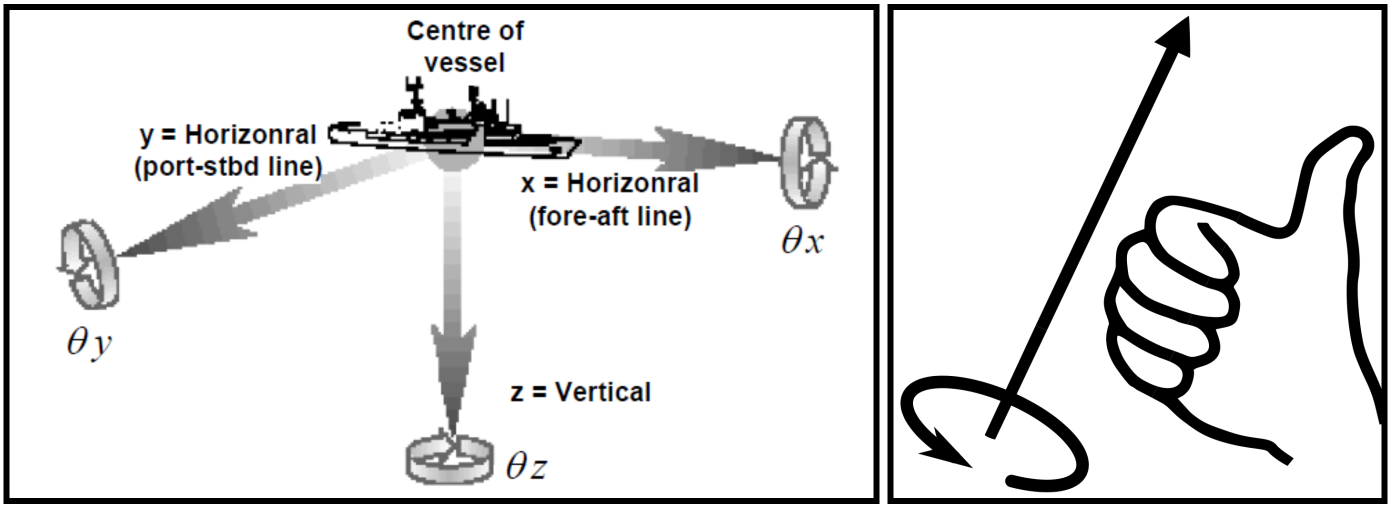

Figure 4. Example 'right-handed' coordinate system with +X forward, +Y to starboard, and +Z down, such as the convention used by Kongsberg. Reson uses another 'right-handed' coordinate system with +X to starboard, +Y forward, and +Z up. Under any orientation, the rotations about these axes must be described using a consistent sign convention, such as the 'right-hand rule' for positive rotation. (Left image: Applanix. Right image: commons.wikimedia.org/w/index.php?curid=6844647)

				Correction 1 (MRU =COG)		
				Y+ (bow)	X + (SB)	Z +(down)
	Offset depositions			-49,914	1,593	-6,166
	Multiplikator depositions			1	-1	-1
	Ship Coordinate System			**Correction 1**		
	X+ (bow)	**Y+ (PS)**	**Z+ (up)**	**X+ (bow)**	**Y+ (Sb)**	**Z+ (down)**
JAV_PS	33,554	6,147	12,799	-16,360	-7,740	-6,633
JAV_SB	33,577	-6,102	12,807	-16,337	4,510	-6,641
MS	80,922	0,000	12,801	31,007	-1,593	-6,635
JAVH	0,000	0,000	8,337	-49,914	-1,593	-2,171
DGPS_SB	54,867	-4,685	18,615	4,953	3,092	-12,449
SVSND	72,596	-0,094	0,829	22,682	-1,498	5,338
FWDSO	73,778	0,056	0,894	23,863	-1,648	5,272
GDS_01	67,976	1,764	0,055	18,062	-3,357	6,112
ITC_01	66,418	0,367	0,058	16,504	-1,960	6,108
JAVBUG	80,891	0,207	12,734	30,976	-1,800	-6,568
KIEL01	60,216	0,177	0,704	10,301	-1,770	5,463
KIEL02	28,392	0,184	0,609	-21,523	-1,777	5,558
DGPS_PS	54,838	4,704	18,646	4,924	-6,297	-12,480
SPEEDLOG	70,184	0,446	0,075	20,269	-2,039	6,091
TM52UK01	75,798	-0,290	5,916	25,884	-1,303	0,251
GTM54UK01	70,525	-1,461	5,495	20,610	-0,132	0,672
Center Top MRU 5	49,914	-1,593	6,166	0,000	0,000	0,000
Center 710 RX	67,366	0,687	0,064	17,452	-2,279	6,102
Center 710 TX	68,755	0,531	0,073	18,840	-2,123	6,094
Center 302 RX	66,853	0,012	0,057	16,939	-1,605	6,109
Center 302 TX	68,802	-0,272	0,073	18,888	-1,321	6,094
EA 38 kHz	68,769	1,123	0,068	18,855	-2,716	6,098
EA 12 kHz	68,541	0,911	0,072	18,627	-2,504	6,095
EA 200 kHz	68,537	1,333	0,066	18,623	-2,926	6,101
EA 12 kHz	68,107	1,120	0,065	18,193	-2,713	6,101
KNUD	66,183	0,628	0,049	16,269	-2,221	6,117
Seapath center	48,895	0,043	25,989	-1,019	-1,635	-19,823

Figure 5. The survey may be conducted using axis and sign conventions (set by a company protocol) that differ from the desired reporting convention. The survey report should clearly present any transformations that were applied to arrive at the final MBES offsets. For instance, this example shows the conversion of sensor locations from the native survey reference frame (with origin on the stern, centerline, at keel height, with +X toward the bow, +Y to port, and +Z up) to the desired mapping system reference frame (with origin at the MRU, +X toward the bow, +Y to starboard, and +Z down).

4. Images

a. The survey report must include images of the surveyed items with clear indications of which features and targets were measured. These images are instrumental in helping readers to interpret the results (e.g., configuring antenna phase center height from measurements on the antenna base) as well as aiding future surveyors in identifying benchmarks to re-establish the vessel frame.

b. Images in the report should be included at appropriate levels of detail that will help readers unfamiliar with the vessel grasp the general layout as well as the detailed orientations of sensors. In all cases, the images must include notation on the viewer's orientation relative to the vessel (e.g., 'looking aft').

c. A complete report will include 'overview' schematics of general locations for areas of survey activity (e.g., indicating the approximate locations for antennas, motion sensors, and transducers) as well as detailed diagrams and images (e.g., schematics of a transducer gondola and pictures of the survey targets on each transducer).

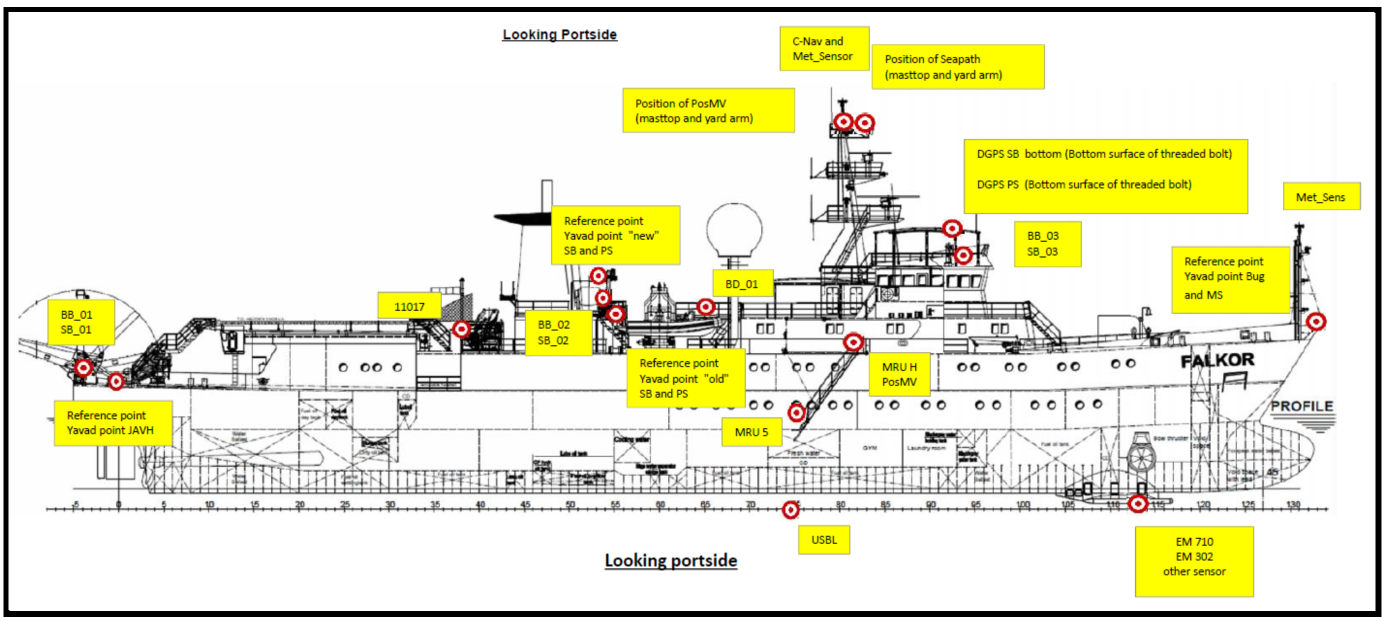

Figure 6. A vessel overview diagram that gives the reader a clear sense of the general layout of sensors. Even though it is obvious in this example, the image is labeled with the viewer's orientation (looking toward port). In this example, results for each sensor are presented later in the report with appropriately detailed images and annotation. (Image: Fugro)

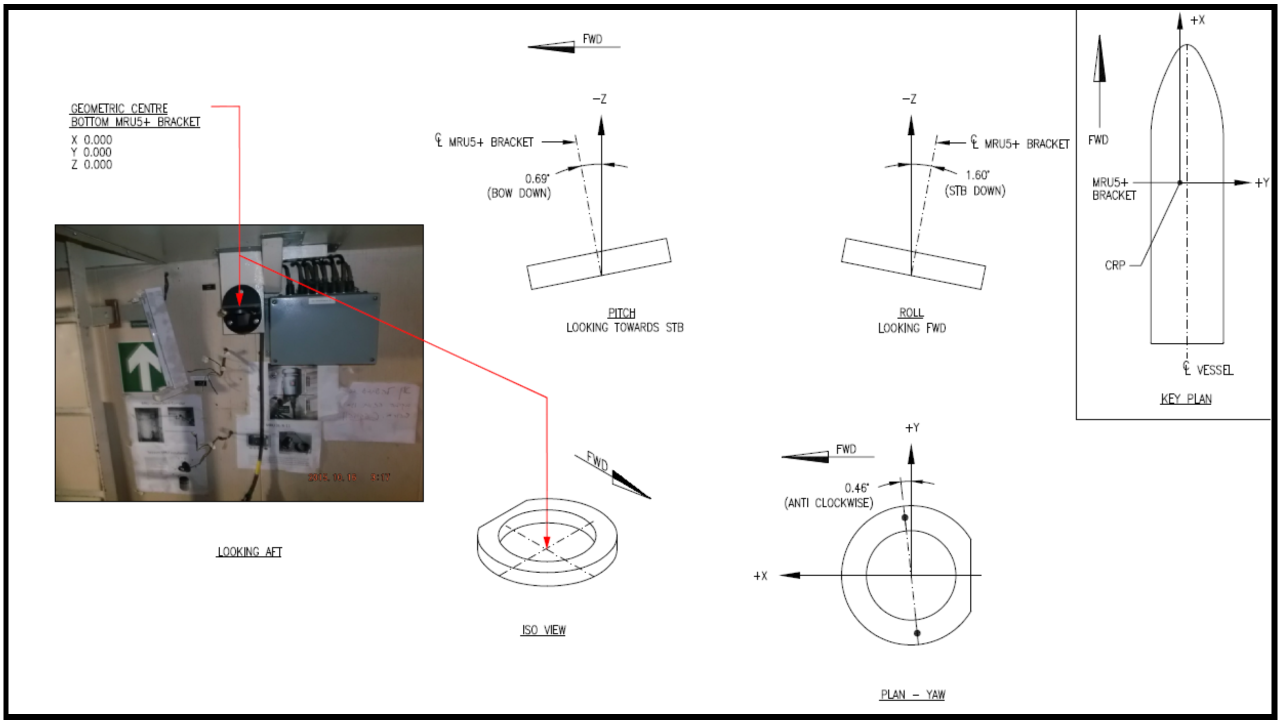

Figure 7. Detailed images and survey results for a motion sensor bracket. The center bottom of this bracket coincides with a designated target on the motion sensor housing (after installation), and is used, in this case, as the origin of the mapping system reference frame. The bracket's general location on the vessel is noted in the key plan, and all images are labeled with the viewer's orientation. All linear and angular survey results are clearly described with reference to the major axes. This combination of views and notes helps all readers to readily understand the orientation of this sensor bracket in the mapping system reference frame, leaving practically zero opportunity for misinterpretation. (Image: Parker Maritime)

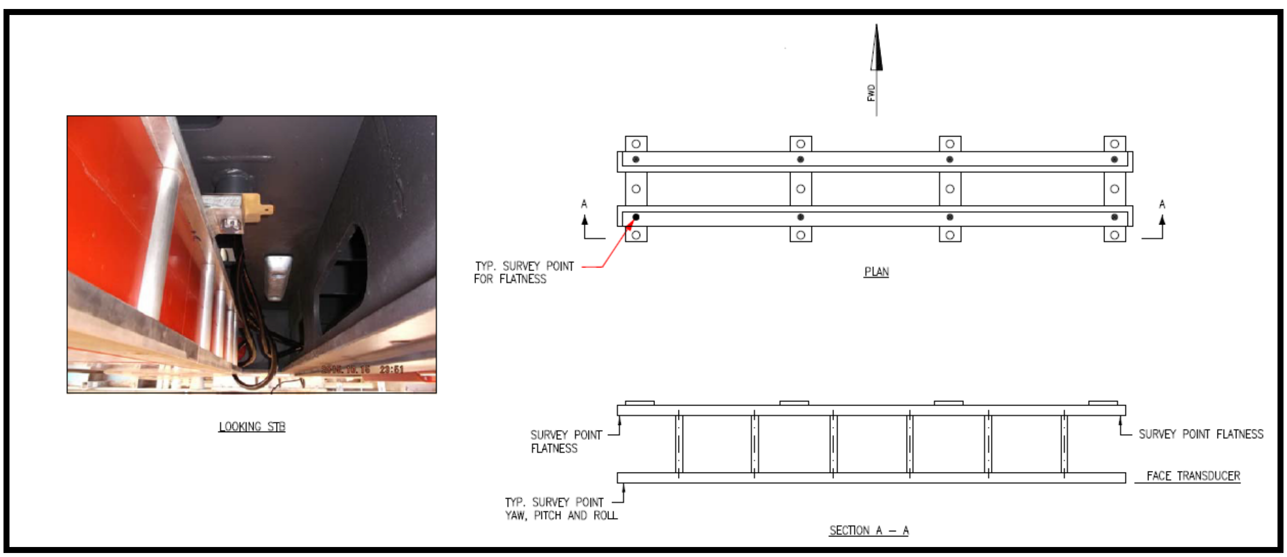

Figure 8. This schematic clearly describes the difference between points surveyed for transducer array flatness and those surveyed for angular offsets. The reader can better understand the survey process, clearly visualize the difference between these sets of measurements, and confidently interpret the correct set for configuration. (Image: Parker Maritime)

5. Sigma / uncertainty of the survey results

a. The survey report must include descriptions of the estimated uncertainty or maximum potential error in the final results. Ideally, the total propagated uncertainty is calculated and presented for each offset.

b. Copies of relevant instrument calibration certificates should be included in all reports.

c. Manufacturers of all multibeam echosounders and positioning / attitude systems installed in the UNOLS fleet provide guidance for the maximum allowable uncertainty in surveying their linear and angular offsets. Survey results exceeding these thresholds may compromise the bathymetric data on a fundamental level. In this case, additional measurements must be taken to satisfy the manufacturer's uncertainty requirements and the updated results must be presented in the final report.

Measurement Precision and Uncertainty
Coordinate uncertainty values are based on fit to the previous survey values and may be more or less than shown, there are (Table 3) Several outliers at PBM 1 and 13.

Region to Region, i.e., Reference Plate to antennae, EM122 TX/RX and other hull features:
$X \leq 5$ mm
$Y \leq 4$ mm
$Z \leq 5$ mm

TABLE 1- POTENTIAL UNCERTANTY

FEATURE	Azimuth	Pitch	Roll
HIPPIE	N/A	±0.100°	±0.100°
PHINS	±0.25°	±0.25°	±0.25°
MRU	±0.25°	±0.25°	±0.25°
EM122 TX	±0.006°	±0.002°	±0.15°
EM 122RX	±0.011°	±0.028°	±0.001°

Figure 9. Descriptions of estimated uncertainty in linear offsets (left) and angular offsets (right). These values are ideally calculated for each result, as for the table (right), and described with some confidence level for comparison to the manufacturers' requirements for each sensor. (Images: IMTEC)

6. Second review before submission

a. The survey report must be reviewed completely before submission to the vessel operator. The review process must ensure that a ‘new’ reader who is generally familiar with mapping systems, but unfamiliar with the particular vessel, can confidently and correctly interpret the report for configuration of each sensor.

b. At a minimum, the report must present the criteria #1-5 outlined above; moreover, consistent application of these guidelines will significantly streamline this review.

c. The end goal of the second review is to rectify potential errors ahead of delivery to the client. At a minimum, errors identified by the client will require a revised report; errors not caught by the client may be carried into the mapping system configuration and seriously compromise data quality.

d. Ideally, the surveyor has sufficient time to complete their reporting and discuss the results with the client well ahead of mapping system configuration and calibration. If it is absolutely necessary to deliver preliminary results (e.g., for an imminent at-sea calibration effort), these numbers must be reported in a way that very clearly warns all users of their preliminary status. The final report must state when preliminary results were delivered and clearly explain any differences from the preliminary results. These steps are critical for the client in managing any impacts of these differences and planning, as needed, to reconfigure and recalibrate with the updated results.

Example table of mapping sensor results

The ultimate purpose of the VSR is the confident and correct interpretation of the survey data for mapping system configuration. Building on criteria #1-6 presented above, this is best addressed with a simplified table of results for the relevant sensors using the chosen MBES manufacturer's reference frame and sign conventions. This table may be presented at the beginning or end of the report and only summarizes, rather than replaces, the more detailed survey data throughout.

Table 1. Example mapping sensor offsets from a chosen origin using consistent axis and sign conventions. This table summarizes the more detailed survey results presented elsewhere in the report. While these final numbers may be used directly for configuration, the reader must still carefully consider how the offsets will be applied among the sensor software packages to avoid doubling or cancelling the offsets. The items in the left column are examples only, and the final offsets required for configuration may differ by system; this should be clarified by the client. For example, manufacturers of higher-frequency echosounders may require a transducer bracket 'reference point' instead of the center of each array face; the client and surveyor must identify these items in planning the survey. Installations on adjustable rams or drop keels should include separate results for each standard position used for mapping (e.g., recessed and extended, plus any intermittent standard positions).

R/V ________	**X**	**Y**	**Z**	**ROLL**	**PITCH**	**HEADING**	**Notes**
Sign convention	Positive forward	Positive to starboard	Positive down	Positive with starboard side down	Positive with forward side up	Positive with forward side to starboard	
Units	meters	meters	meters	degrees	degrees	degrees	
Origin (chosen feature)	0.000	0.000	0.000	N/A	N/A	N/A	
TX array (center of array face)							
RX array (center of array face)							
GNSS antenna 1 (phase center)				N/A	N/A	N/A	*Phase center height is ____ m above the survey point (source: _______)*
GNSS antenna 2 (phase center)				N/A	N/A	N/A	
Motion sensor (survey target on sensor housing)							
Center of gravity (approx. loc. for heave filtering)							
Additional sensors							

Contact information

The Multibeam Advisory Committee can be reached by email at **mac-help@unols.org** to discuss these recommendations, review survey reports, and offer guidance with planning new surveys of mapping systems in the UNOLS fleet. For additional reference, the MAC website (**www.mac.unols.org**) presents a wide range of reports covering MBES sea acceptance testing, calibrations (‘patch tests’), swath accuracy and coverage assessments, and noise evaluations conducted on vessels throughout the UNOLS fleet since 2010.