NOAA SHIP *RAINIER* LAUNCH
2801, 2802, 2803, AND 2804
EM2040 ACCEPTANCE TESTING

With Hydrographic Systems and Technology Programs Multibeam Sonar Acceptance Procedures

**DATES**
2017 September 12 to September 21

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NOAA Office of Coast Survey
Executive Summary
We installed four Kongsberg EM2040 multibeam echo sounders on each of Rainier’s four hydrographic survey launches from September 12th through September 13th in Everett, WA. We accomplished the test and qualification of these systems on Puget Sound from September 14th through September 21st.

Conditions were generally agreeable for testing with some environmental effects potentially affecting a limited set of noise tests. All systems were successfully integrated. Measured performance is in compliance with vendor specifications and is suitable for NOAA hydrographic surveys.

Significant Findings and Recommendations

1. Four systems were installed and integrated according to HSTB recommendations and performed as expected.
2. Sounding quality and object detection of these multibeam systems is significantly higher inside 65° from nadir. We recommend limiting the operational swath to 65° in most cases.
3. Sonar systems met complete coverage survey requirements when operating at 7.9 knots. Survey operations at speeds up to 10 knots will likely meet complete coverage requirements. When conducting object detection surveys, we recommend limiting survey speed to 8 kts and ensuring swath width does not exceed 65°.
4. Accuracy lines were used to generate backscatter mosaics, allowing us to further examine differences between operating modes. We processed backscatter mosaics, establishing cross-correlation values between vessel, pulse length, and frequency.
5. The Rainier hydrographic launches appear to have a relatively high noise floor at 400 kHz. Bottom-bounce radiated noise from the propulsion may contribute to this.
6. The acceptance testing schedule occurred concurrently with an off-shore project that did not require launch work. This allowed for sufficient time to complete testing and conduct initial analysis on-site with minimal impact to sea days.
7. The Shilshole reference surface, while valuable for its historical data, may have significant freshwater input from the Ballard locks and thereby experience oceanographic variability that is not ideal for calibration work.
8. We recommend a 7 millisecond value for motion time delay into SIS for Rainier EM2040s.
9. SV casts must be extended past the operational depth of the system prior to loading to SIS. CTD profiles that fail to cover the full depth of the survey area, extended or otherwise, may result in anomalous absorption values and interfere with reported depths.
10. Because of the 7 ms timing offset between POS and the 2040s, any post-processed navigation and attitude solution should either account for this offset on export, or only the navigation (and not attitude) should be applied to the bathymetric data in post-processing. We recommend the latter.

This project constitutes a work of the United States Government and is not subject to domestic copyright protection under 17 USC § 105.
The analysis, recommendations, and conclusions included in this report were conducted to support test, evaluation, and operational readiness of this installed system and do not constitute in any way endorsement or recommendations for current or future procurement or any commercial developmental recommendation.
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1 General Overview
The four Rainier launches were constructed in 2008. They are 8.6 meters long with a 3.5 meter beam and are driven by a single 490 hp diesel engine. The vessels have a cutout in the keel that houses a small well for mounting a mapping echo sounder. Kongsberg Underwater Technologies Inc. in Lynnwood, WA designed and built a mount during the fall of 2016 to fit the well and to accommodate the Kongsberg EM2040. We tested the initial configuration of the Kongsberg echo sounder mount on a Fairweather launch during February 2017 [1]. Following the initial test, small modifications to the mounts were made to better fit the systems to the sonar wells. Kongsberg Underwater Technologies Inc. in Lynnwood, WA designed and built a mount to fit the launch wells which was evaluated, modified, and deemed acceptable during May of 2017. The sonar systems were installed on all four Rainier launches on September 12th and 13th.

We conducted acceptance tests for the four new EM2040s in Puget Sound between September 14th and September 21st 2017. The participants in this acceptance work included Coast Survey and OMAO personnel, as well as Kongsberg representatives. Coast Survey’s Hydrographic Systems and Technology Branch (HSTB) was represented by LCDR Samuel Greenaway, Glen Rice, and LTjg Shelley Devereaux. LT Steven Loy represented Rainier and OMAO. Kongsberg was represented by Travis Eliasen, Tony Dahlheim, and Chuck Hoeing. Additional ship personnel and Pacific Hydrographic Branch representatives assisted with data acquisition allowing two to three boats to be deployed during most days.

This report consolidates the results from acceptance testing for all four launches into a single report. Throughout this document the individual launches are referenced only by their hull numbers.

2 Overview of schedule and conditions

2.1 Preplanning
Planning for the acceptance trials evolved with personnel availability and weather. HSTB personnel coordinated with the ship’s command and Coast Survey to establish a plan for acceptance testing.

2.2 Executed Schedule
- Tuesday, 12 September
  - Transited launches from RA to Everett/Dagmar’s
  - Begun work on sonar installs for 2801 and 2802
- Wednesday, 13 September
  - Sonar installs for 2803 and 2804
  - Completed all sonar installation
- Thursday, 14 September
  - RA 2801 and RA 2802 depart from Dagmar’s to Shilshole
  - RA 2801, RA 2802: Patch test values
- Friday, 15 September
  - RA 2803 and RA 2804 transit from Dagmar’s to Shilshole
  - RA 2804: Patch test, GAMS
- Saturday, 16 September
RA 2803: Patch test, GAMS, Extinction, Shallow Noise

- Sunday, 17 September
  - RA 2801: Accuracy test, Reference Surface, Deep Noise, Patch test, GAMS

- Monday, 18 September
  - RA 2802: GAMS, Accuracy test, Reference Surface, Patch test confirmation, Deep Noise test
  - RA 2803: Accuracy test, Reference Surface, Roll Timing

- Tuesday, 19 September
  - RA 2804: Extinction, Shallow noise, Deep Noise, Accuracy, Reference Surface, Roll Timing
  - RA 2802: Extinction, Shallow noise, Deep Noise, Roll Timing
  - RA 2803: Deep Noise

- Wednesday, 20 September
  - RA 2801: Extinction, Shallow Noise, Roll Timing

- Thursday, 21 September
  - Launches returned to Rainier

3 Pre-Installation Testing

3.1 Test Data Processing Workflow

No preparatory workflow testing was completed for the Rainier launch acceptance. Because the EM2040 and other Kongsberg multibeam echo sounders are in use within the NOAA fleet with the same configuration, both the ellipsoid and water-level referenced workflows have been validated with current processing workflows.

3.2 Determine data rates and file size

An estimate of data volume accumulation as a function of time, depth, and configuration can be helpful for survey planning and ensuring the needed data storage is available during survey operations. Data rates were determined using data collected during extinction testing. Record sizes and ping rates were combined to estimate a data volume accumulated as a function of depth. These estimates include the vessel attitude, navigation, attitude velocity, backscatter, both the fully ray traced and motion corrected bathymetry and the range / angle data, and the system status, settings, and uncertainty. Figure 1 shows data rates without the water column record. Figure 2 includes the water column record.
Figure 1 - Data collection rates for launch 2802 without water column data, similar to all launch results. Note logarithmic y-axis.

Figure 2 - Data collection rates for launch 2802 with water column data. Similar results for all launches.

Table 1 shows data rates for select depths for the 300 kHz mode in for easy reference.

<table>
<thead>
<tr>
<th>Water Depth (Meters)</th>
<th>Bathymetry Data Rate (MB/hour)</th>
<th>Water Column Data Rate (MB/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1,300</td>
<td>37,500</td>
</tr>
<tr>
<td>50</td>
<td>750</td>
<td>25,500</td>
</tr>
<tr>
<td>100</td>
<td>425</td>
<td>11,000</td>
</tr>
<tr>
<td>200</td>
<td>325</td>
<td>15,750</td>
</tr>
</tbody>
</table>

Table 1: Data Rates for 300 kHz setting for selected depths

3.3 Operational hazards
No current environmental or safety regulations or hazards restrict use of this multibeam echo sounder.
3.4  **Determine user configurable system settings**
The user configurable settings are as expected from past experience. Users should review the EM2040 SIS manual for a description of many of the available settings.

4  **Configuration**

4.1  **Sonar installation parameters**

4.1.1  **Vessel Survey and Reference Frames**
No new vessel dimensional offset survey of the *Rainier* launches was conducted in association with the installation of the new EM2040 multibeam echo sounders. Because of the relatively short baselines between the multibeam transducers, the POS MV IMU, and the POS MV antennas, the offsets were determined by combining the previous survey (National Geodetic Survey, March, 2008), the engineering drawings (Figures 3-7) of the echo sounder mount, and a few additional measurements. We measured the mounting bolt holes for the mounting plate inside the hull relative to the IMU (Figure 8). We calculated the transducer offsets from this attachment hole from the engineering drawing of the mount (Figures 6 & 7). All transducers are mounted in a “forward” convention, with the transmitter cable on the port side, receiver cable output towards the bow.
Figure 4 - Sonar plate offsets, view from above sonar face

Figure 5 - Sonar plate offsets, side view
Figure 6 - Sonar plate offsets, IMU to mounting plate bolts

Figure 7 - Sonar plate offsets, IMU to mounting plate bolts
To simplify the downstream workflow, we chose the system reference point and reference frame as to be centered on and aligned with the EM2040 transmit transducer [2]. Having the positioning system and the multibeam system in the same reference system eliminates the need for different CARIS HIPS HVF entries depending upon the vertical-control workflow (e.g. ellipsoid vs water-level control as
discussed in [3] and [9]). We entered the offsets between the EM2040 transmit transducer and the POS MV sensors (IMU and antennas) into the POS MV. The patch test values (the residual misalignment between the multibeam and attitude sensor) were entered into the POS MV as well. SIS contains only the offsets between the transmit transducer and the receiver and the location of the waterline. We re-ran the GAMS calibration after the POS MV reference frame was rotated with the patch test values to align the antenna baseline in the new frame.

Because the POS and Kongsberg frame are explicitly colocated and aligned upfront, the CARIS HIPS HVF is relatively simple. All fields “are zeroed” with the exception of the SVP, TPU, Waterline, and Dynamic Draft fields. SVP1 has all zeros, but SVP2 has the same offsets between the transmit transducer and receive transducer as is entered in SIS. The TPU fields are largely the same as previously configured, as is the Dynamic Draft table; in the latter, the IMU is essentially directly above the transducer, so the reference point change is insignificant. The waterline is the same as the entry as is in SIS with “apply = No.” An example HVF is included in Appendix 10.2.

Static Draft and Dynamic Draft were confirmed by Rainier personnel and were not examined during acceptance testing.

4.1.2 Data Flow Configuration

We configured SIS to output data though the Installation Parameters, PU Communication Setup, Output Setup dialog to the local port 16119. The data was then forwarded to Hypack and Sound Speed Manager using the Kongsberg DataDistribution.exe program, which was set to autostart upon boot of the SIS workstation. Upon initial boot of SIS, this module occasionally appeared to be blocked, as indicated by red IP address fields. Selecting the fields remedies the problem. This is assumed to indicate ports that have been held by SIS and selecting them allows for data to move through the ports. The same issue was observed during the Fairweather sonar testing, and was confirmed as a known issue with Kongsberg. Figure 10 shows the survey system configuration.
Figure 10 – Rainier launch survey system configuration as of the acceptance cruise.

Water column logging through SIS is licensed for the Rainier launches. Logging water column data produces a separate raw *.wcd file containing water column records. In addition, we configured this file to contain the attitude, position, system settings, installation parameters, and sound speed profiles. While these records are duplicates of some of the bathymetry file contents, repeating these records in the .wc makes these files complete and stand-alone and eliminates the cases where pairing or merging the *.all and *.wcd files is necessary.

4.2 Ancillary equipment setup

4.2.1 Position and Attitude

The POS MV was configured to send navigation (NMEA INGGK string) and attitude (Simrad 3000 (Tate-Bryant)) through serial cables to the EM2040 TRU. An Ethernet connection from the POS MV to the TRU was included for attitude velocity. The POS MV lever arms and rotations were configured with the 2040 transmitter as the reference point as described in 4.1.1. We confirmed proper connection to the primary / secondary antennas, and used an NTRIP RTK input from local Plate Boundary Observatory (PBO) stations in these tests as Base 2. We verified that position and attitude were equivalent between SIS and the POS MV. The POS MV firmware for the PCS and GNSS cards are the latest available versions at the time of the trials: MV-POSView Version 9.12, POSMV Firmware Version 9.13.
4.2.2 Surface Sound Speed
A Reson SVP71, mounted on the same mounting plate as the EM2040, provides surface sound speed. Because the SVP71 could not be directly connected to the EM2040, Kongsberg provided an adaptor box that powers the SVP71. The SVP71 outputs an AML SV message for ingestion into the SIS workstation. The SIS low pass filter was set to 5 seconds from the default 60, which we have previously found to be more appropriate for our field work. Further discussion of the surface sound speed is in Section 6.2.

4.2.3 Profiling the Physical Characteristics of the Water Column
As is typical aboard NOAA hydrographic launches, a winch-deployed Seabird CTD profiled the physical characteristics of the water column. Sound Speed Manager (SSM), a project merging the SS Manager, software supported by the University of New Hampshire, and Velocipy, software supported by HSTB, was installed and used on all platforms. In all cases the CTD data were downloaded from the CTD and sent directly to SIS over the network switch. Direct export of the CTD data to SIS worked smoothly, though the SIS operating system requires the user to extend casts to ensure full coverage of the survey area. Manual extension using a deeper reference cast or a synthetic cast from the World Ocean Atlas can be applied up to 5,500m in SSM, though export of all sound speed profiles (.asvp) are automatically extended to 12,000 m before transferring file to SIS. During sonar acceptance trials, there were multiple instances of a cast not being extended before being exported to SIS. This resulted in abnormal absorption coefficient values when operating in areas deeper than the most recent reference cast, displayed as a saturation in the water column view (Figure 11). This cause of this issue was confirmed by logging through an area with greater depths than the last cast, and easily corrected by extending the cast before sending to SIS.

Figure 11, Launch 2803 survey depth extends beyond reference cast
4.2.4 Hypack
Hypack was configured to accept data from SIS for real time display and communication with the coxswain. All multibeam data were logged through SIS. We recommend that SIS be used for all future operational data logging as well.

4.2.5 Vertical Control
Vertical control for all acceptance work was either through RTK as supported by the local PBO stations, or to the survey time water level in the case of extinction testing where the transducer to seafloor separation is of primary consequence. Where a comparison to previous surveys was required, VDatum was used to shift from the ellipsoid to the applicable datum.

RTK corrections were provided via HSTB supplied Verizon MiFi using the PBO NTRIP caster. A field laptop running the Lefebure NTRIP client sent RTCM 3 messages to the POS MV.

5 Alongside Testing

5.1 User interface and system control
The user interface and system controls for the EM2040 operated the same as for previous versions of SIS and previous acceptance tests. SIS 4.33.0 was installed on all EM2040s.

5.2 System health self-tests
SIS Built In Self Tests (BIST) of all types were performed for both systems. All BIST tests passed the preset Kongsberg criteria.

5.3 Evaluate stave data
See the discussion of BIST tests in 5.2.

5.4 Backscatter quality assessment
Backscatter quality was not assessed while alongside. Please see 6.6 for a discussion of backscatter assessment and while underway.
6 Underway Testing

Patch Test

Patch testing was conducted in Appletree Cove off of Kingston, WA (Figures 12 and 13). Proximity to the ferry route and traffic presented some operational challenges, but overall the location was appropriate for patch tests and produced satisfactory results. Patch test values were derived for each value after the applicable test in Qimera and/or CARIS, depending on the personnel and equipment aboard the vessel. These values were then entered into SIS before performing the next test. Once all tests were completed the values were transferred to the POS MV, but with the opposite sign to accommodate rotating the IMU relative to the transducer rather than rotating the transducer relative to the IMU. The primary GNSS lever arm was not updated to account for this rotation directly, but the lever arm was confirmed using the POS real-time lever arm quality confirmation tool.
The resulting patch test values as entered into the POS MV for each launch are described in Table 2.

<table>
<thead>
<tr>
<th>All values are in degrees</th>
<th>2801</th>
<th>2802</th>
<th>2803</th>
<th>2804</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>-0.200</td>
<td>0.200</td>
<td>0.000</td>
<td>-0.720</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.10</td>
<td>0.800</td>
<td>0.580</td>
<td>-0.300</td>
</tr>
<tr>
<td>Yaw</td>
<td>-0.220</td>
<td>-0.625</td>
<td>0.500</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Table 2 - Patch test values for each system as entered into the POS MV.

While gross timing and time synchronization errors are rarely a problem with current survey systems, Kongsberg multibeam echo sounders use position and attitude records that do not contain a timestamp, and instead count on minimal time delay in transmission and perfect discipline of the multibeam clock through a ZDA NMEA string and a 1 PPS pulse. A small time delay has been observed with POS-MV/Kongsberg echosounders on other NOAA vessels but the source of the time delay has not been identified. To check for a time delay, we used the method outlined in [4] using the correlation between a bathymetric roll artifact and the motion time series to solve for timing errors. Given the innate stability of the launches, we created a wake-generated roll environment to capture motion time delay. For Rainier launch EM2040s we observed a small time delay, generally between 7 ms and 11 ms depending on the vessel and dataset used. John Hughes Clarke notes that this is similar to the 7 millisecond to 10 millisecond time delay observed with Navocean HSLs with a POS MV, and also on par with values derived for Fairweather launches. Though there were a range of timing offset results, visual inspection of the surfaces confirmed that using the 7 millisecond offset provided the most consistent and satisfactory results. We recommend using a 7 millisecond value for motion time delay for all of the Rainier EM2040s and entered this offset into SIS. While this value was not in the system during tests at the time of acceptance trials, the impact of this correction is small and we do not recommend post-applying this correction to any data already collected.

6.2 Acquire Reference Data Set

During this test a reference surface and sets of crosslines are collected to look for biases across the swath in different modes. We collected a dense data set for reference, and then varied system settings,
such as frequency and pulse length, for different crossline. In this case the accuracy line was used as a crossline, and run in both directions with each setting combination for improved statistics.

The IHO uncertainty standards (and similarly the NOAA specification) contain both a depth dependent and depth independent error component; the depth independent part \((a\) in Equation 1) is intended to account for error sources such as vertical control and draft measurement, the depth dependent factor \((b\) in Equation 1) accounts for integration, environmental, and echo sounder performance.

Equation 1: Vertical uncertainty limit equation from both IHO and NOAA Specifications.

\[
\text{Uncertainty Limit} = \sqrt{(a^2) + (b \times d)^2}
\]

Because of the nature of these tests, there was little variation in the depth independent error parameters, so it is more appropriate to evaluate the performance only against the depth dependent component (i.e. the ‘b’ parameter). For both IHO Order 1 and NOAA specifications, this is 1.3% of water depth. For reference, at this location, 1.3% of depth is approximately 0.2 meters.

We used the Shilshole Reference Surface for these tests. This area, located just off entrance to the Ballard locks and the Shilshole Marina, is an established test location within NOAA. We chose this area for accuracy testing and developing reference surfaces primarily because historical data is available for comparison to both historical data and the EM2040 installations for Fairweather launches, conducted in May 2017. All four vessel ran all three frequency settings (200, 300, and 400 kHz) for the EM2040 at this location while also varying the pulse length settings for accuracy tests.

While the location is convenient to vessels housed inside the locks or at Shilshole Marina, a potential downside to using this location for calibration work is the fresh water output from Lake Washington and Lake Union. While this was not observed during testing for Rainier EM2040 testing in September, sound speed variance was a considerable factor during Fairweather’s EM2040 testing in Shilshole Marina [8]. Figure 14 shows an example of the variability in the surface sound speed for a single line in Shilshole.

![Figure 14 - Launch 2803 Accuracy Line 0008 Surface Sound Speed. Both the measured and filtered (used) values are shown.](image)
SIS filters the surface sound speed to remove erroneous values that might occur due to bubble sweep down, and uses this filtered sound speed for beamforming. Using this filtered value likely had a small impact on beamforming and the resulting system resolution and side lobes, but proves valuable in dynamic oceanographic environments.

![Figure 15](50 cm reference surface, launch 2803. Depths in meters.)

We compared the bathymetric data on the ellipsoid datum in Qimera using the real time vessel height from the POS MV, which was aided by RTK.

A brief summary of the wind conditions during accuracy testing is in Table 3. Weather was generally consistent between all vessels, with the exception of launch 2804. See Section 3.2 for the executed schedule of data collection.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Wind During Accuracy Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2801</td>
<td>SSE 5 - 9 kts</td>
</tr>
<tr>
<td>2802</td>
<td>S 6 - 11 kts</td>
</tr>
<tr>
<td>2803</td>
<td>SSE 7 kts</td>
</tr>
<tr>
<td>2804</td>
<td>S 2 kts</td>
</tr>
</tbody>
</table>

Table 3 - Wind conditions during acquisition of accuracy lines.

A summary of these accuracy line data is provided here with all results in appendix section 10.3. In general, all four EM2040s performed as expected. In shallow water testing, higher frequencies and shorter pulse lengths (Figure 16) produce better results when compared to results from lower frequencies and longer pulse lengths (Figure 17). The results of the depth accuracy biases across each swath were within IHO Order 1 within 65°. Biases outside of 65° were characteristic of sound speed errors.
Figure 16 - Across swath accuracy plot as a percentage of depth for Launch 2802 at 400 kHz with Short CW pulse. All soundings are shown with grey dots, and the purple area is 95% confidence interval. Blue line is average of all soundings, green dashed line is the 0.6% water depth for IHO special order, and the grey dashed line is 1.3% water depth for IHO Order 1.

Figure 17 - Across swath accuracy plot as a percentage of depth for Launch 2802 at 200 kHz with a long pulse.

6.3 Noise floor testing
The purpose of noise testing is to assess sources of acoustic interference that may impact data quality. The successful detection of the seafloor is dependent on the strength of the seafloor echo relative to other signals that characterize the background noise level or noise floor. Noise can be acoustic, either environmental or mechanical (including self-noise from the vessel), or electrical and originate inside the echo sounder electronics. Signal processing techniques internal to the echo sounder can also introduce noise, such as side lobes produced by different filters. These tests seek to establish a baseline noise level providing for the opportunity to identify significant changes in the future. Some noise sources,
such as environmental noise from bubbles going under the hull, may artificially boost the noise floor during these tests.

Figure 18 shows the vessel speed as a function of engine revolutions per minute (RPM). Throughout this analysis noise is plotted as a function of engine RPM. While engine RPM may not be as intuitive as vessel speed, speed can also be affected by the relative weather direction which cannot be controlled during testing. Environmental impacts on speed as a function of RPMs is evident in some results, such as launch 2802 in deep water.

![Figure 18 - Vessel speed over ground as a function of engine RPM during noise testing for all launches. DIW is “dead in the water”.

Noise floor testing was completed in both deep and shallow water to look at changes in performance. In deep water, electronic, direct path and flow environmental noise are dominant. These noise sources are also present in shallow water with an additional component of radiated noise travelling back to the receiver via a bottom bounce path. Deep and shallow noise tests were conducted between Saturday, Sept 16th and Wednesday, September 20th. We recorded ten BIST RX Noise and RX Noise Spectrum tests for each engine RPM in SIS, and also recorded water column data at each speed while in passive (no transmit) mode. Passive water column noise is shown as averaged along each beam as a time series of all pings. These data are then also averaged by each beam for each speed. Averaging by beam assumes that noise is at a consistent angle relative to the vertical, and in the case where noise is transducer relative (such as coherent noise on all channels appearing at boresight) the noise may be smeared across several angles as the vessel rolls. Averaging was completed in the linear domain after data outside of 3 standard deviations was removed from the time series. EM2040 analysis on passive water column is limited to the even pings because the odd pings did not present usable data due to a firmware problem. This problem was reported to Kongsberg during the fall 2016 acceptance testing aboard NOAA Ship *Thomas Jefferson*. This problem does not exist for water column collected in active mode.
BIST noise tests are governed by preset Kongsberg settings, but passive water column is sensitive to user settings. The frequency mode is particularly important as it changes the echo sounder’s sensitivity to noise at particular frequencies. The maximum range setting governs the record length (which would be range scale if transmitting), and shorter record lengths open gaps between water column records where burst noise might occur. For these tests a maximum “range” of 100 meters was selected.

Deep noise testing was conducted either adjacent and to the northwest of the Shilshole reference surface in approximately 200 meters of water or on the other side of the sound in the mouth of Port Madison in similar water depths. Shallow water noise testing was conducted in approximately 10 meters of water on the northern side of Port Madison.

Weather, as an environmental factor for raising the noise floor, also affects these results, although heading relative to the weather was not controlled during this testing. Vessel heading was changed to maintain proximity to the same area and depth, and was thus in one of two reciprocal directions. The wind is summarized in Table 4.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Wind During Shallow Noise Test</th>
<th>Wind During Deep Noise Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>2801</td>
<td>SW 4 kts</td>
<td>S 7 kts</td>
</tr>
<tr>
<td>2802</td>
<td>S 8 - 15 kts</td>
<td>S 8 - 15 kts</td>
</tr>
<tr>
<td>2803</td>
<td>S 5 kts</td>
<td>S 8 - 15 kts</td>
</tr>
<tr>
<td>2804</td>
<td>S 8 - 15 kts</td>
<td>S 8 - 15 kts</td>
</tr>
</tbody>
</table>

Table 4 - Wind during noise testing.

In general BIST RX Noise and BIST RX Noise Spectrum tests agreed between launches 2801, 2802, 2803, and 2804. At speed, noise levels were approximately 17 dB higher in shallow water when compared to the same speeds in deep water (Figure 19), and showed no frequency dependency across the bandwidth of the receiver (Figure 20). With the BIST tests, noise levels increased with engine RPM. The passive water column showed the same trend. All launches demonstrated significantly higher noise levels in the passive water column data at 400 kHz frequency. All Additional BIST test results can be found in appendix section 10.4.

Figure 19 - BIST RX Noise Tests for Launch 2801.
A substantial amount of passive water column data was recorded between four vessels: three test frequencies, and two locations (deep and shallow). We set RPM steps at 200 RPM intervals, starting at 600 RPM and continuing to 1400 RPM, roughly corresponding to 1 kt in speed change per step.

All vessels had roughly the same noise floor while dead in the water, whether in deep or shallow water, indicating similar electronic noise environments. In all cases, the baseline water-column noise floor at 400 kHz is approximately 10 dB higher than that at 300 kHz or 200 kHz. In deep water, noise-levels did not generally increase with speed, but did show episodic bursts most likely from wave-slap or other environmental effects. The exception to this is launch 2804, which demonstrated consistently higher noise-levels at all frequencies when operating at 1200 RPM (Figure 21). We suppose this might be due to inherent noise properties of the launch, specifically related to rotational vibrations of the propeller shaft. In shallow water, all vessels demonstrated a sudden increase in noise levels beginning at approximately 900 RPM. This noise was higher at nadir. Both the directional nature of this noise and the higher values in shallow water suggest that the dominant noise in shallow water is from a radiated, bottom bounce path. The likely source of this noise is propeller cavitation. Though this bottom-bounce source dominates noise level in shallow water, the bottom bounce noise-path path likely attenuates in the same way that the bottom-bounce signal does and thus does not have a depth dependent signal-to-noise reduction. This would not be the case were the dominant noise direct path.
Rainier’s launches achieved the same speed as Fairweather’s at a lower RPM, resulting in lower noise levels at survey speed. There are a number of different propellers in service between Fairweather and Rainier launches. For Rainier, 2801 and 2803 have five-bladed propellers (24” diameter, 26.5” pitch, expanded area ratio: 1.0), 2802 and 2804 have four-bladed propellers (25” diameter, 26” pitch, expanded area ratio: 0.85). In addition, the tunnel clearance around the propellers is slightly smaller on 2801 and 2802 than the rest of the series. From these tests, these differences in propeller’s or tunnel on Rainier’s boats do not make obvious differences to the observed noise.

The launches are equipped with independent coxswain fathometers for general navigational use. These sounders can operate in 200 kHz (high frequency) or 88 kHz (low frequency) modes. BIST and passive water column was not collected on Rainier launches while simultaneously operating the coxswain fathometer, but this test was conducted during FA’s sonar acceptance [8]. Results demonstrated that the coxswain fathometer most clearly interferes with the EM2040 when operated in the high frequency mode, and then most clearly when the EM2040 is also operated in the 200 kHz mode. Operation of the high-frequency fathometer interfered at all EM2040 operating frequencies. The low frequency fathometer setting also interferes, but considerably less than the high frequency setting. Where possible, we recommend securing the coxswain fathometer during survey.

6.4 Object detection and recognition

We used several objects within the Shilshole reference surface to measure the EM2040’s ability to detect and depict objects. We chose two objects for their location relative to the standard Shilshole lines and because of their apparent size. Each object was observed with each frequency and we counted the number of soundings both on the object and on top of the object. These counts were then normalized to the number of soundings per square meter, by dividing by an estimated footprint for each object, to make observations between the objects roughly comparable. Within this section, these Objects are identified as Object 1 and Object 2 (Figure 22).

![Figure 22 - The location of Object 1 and Object 2 within the Shilshole reference surface on NOAA Chart 18447.](image)
Object 1 rises 1 meter off the seafloor in approximately 16 meters of water with a footprint of approximately 4.4 square meters (Figure 23). Object 1 was observed at approximately 25° (+/- 5°) and 60° (+/- 2°) for all vessels and frequencies, but the 400 kHz mode did not capture the whole object for the 60° offset. An observation of the “top” of this object was defined any sounding within the IHO uncertainty, which is roughly half of the object height.

Figure 23 - Object 1 as seen in the water column (top) and from above in the 0.5 meter gridded bathymetry (bottom) overlaid on NOAA Chart 18447, which is in feet, and with all other dimensions in meters.

Object 2 was found in 15 meters of water, but only rose 0.5 meters off the seafloor with approximately a 1 square meter footprint (Figure 24). Object 2 was observed at approximately 0° (+/- 12°) and 67° (+/- 1°) for all vessels and frequencies, except 400 kHz for the 67° line because the swath is limited to 60° on either side of nadir. An observation of the top of this object was defined as any sounding within the top half of the object due to its limited vertical extent.

Figure 24 - Object 2 as seen in the water column (top) and from above in the 0.5 meter gridded bathymetry (bottom) overlaid on NOAA Chart 18447, which is in feet, and with all other dimensions in meters.
The swath width was maximized during data collection which has the effect of spreading out the sounding across the swath and slowing the ping rate. Both the 300 kHz and 200 kHz modes were operating at 75° to each side, while 400 kHz is limited to 60° automatically. Because of this effect the 400 kHz modes could not observe objects outside of 60°, but the sounding density is lower with both 300 kHz and 200 kHz.

Figures 25 and 26 are representative of the differences in object detection quality dependent on frequency for Object 1. Table 5 shows the normalized number of soundings used to characterize each object for each vessel and frequency. Figures 27 and 28 show the across-vessel average of the maximum and minimum values with error bars to demonstrate the vessel variation for the number of normalized soundings for each frequency.
Figure 27 - Detections of each object, normalized to soundings per meter, by detection angle.

Figure 28 - Detections on top of object, normalized to soundings per meter, by detection angle.
There is some variation in detections across all vessels, but this is accounted for by change in frequency and corresponding swath width. All frequencies observed the object at 60°, but there were few detections made at 67°. The 400 kHz frequency in swath widths within 65° displayed the highest resolution results, giving clear definition of the object’s footprint. Considering the impact of sound speed on outer swath, we recommended that the swath width generally be limited to 65°.

### 6.5 Sonar Performance Parameters

The usable swath width as a function of depth is important to survey planning, survey quality, and survey efficiency. All launches ran the EM2040 on a gradual slope from depths of 10 meters to 200 meters for all frequencies, in a test area north of Apple Tree Cove on the west side of Puget Sound. This test location did not allow for sonars to run to full extinction, but all frequencies saw a loss of angular swath width at 200 meters. The usable swath width is defined by the outermost good beam on each side of the swath as reported by the multibeam. Because seafloor type has a strong impact on the returned signal level, the achievable swath width does depend on the seafloor type. The identified outermost good beam can still contain noise or an incorrect depth as it has only been designated “good” by the system. In this case, proximity of the test site to the Puget Sound Traffic Lane contributed to some residual noise from vessel wake and ambient fathometer noise transiting in or out of Seattle.

Figure 29 shows a typical extinction plot; all extinction plots are in appendix section 10.5. The 400 KHz mode is restricted to 65 degrees from nadir, the other frequencies were run with an initially wide-open swath. The actual useful swath width as a function of depth will depend on bottom type and environmental conditions, but the results here should be useful for planning. Launch 2803 did exhibit some abnormal restrictions in swath width as a function of depth in depths of approximately 120 meters (Figure 30).
All Rainier EM2040s met or exceeded Kongsberg performance expectations for swath width by depth for a sandy seafloor.

6.6 Backscatter quality assessment

Seafloor acoustic backscatter mosaics are set to become a field unit deliverable in 2018, compelling a backscatter quality assessment as a part of these sonar acceptance trials. The Kongsberg EM2040 sonar does not currently have an accessible calibration file found in the other EM systems (BsCorr.txt) which allows for real time normalization when between swath modes, sectors, and operating modes. It is possible, however, to normalize backscatter products across platforms in post-processing [5]. Given the geographic diversity of project areas, it is unlikely that a single acquisition mode will be appropriate for all survey projects. By comparing the backscatter across the swath over a flat homogeneous seafloor, the backscatter offsets as a function of angle can be determined. Acquiring data in each direction over the accuracy test line provided greater options for analysis, countering the impact of significant environmental noise impacts. We collected combinations of 200, 300, and 400 kHz frequencies with short, long, and frequency modulated pulse lengths. These methods are based on work completed by
Data were acquired at each reference surface for the 200, 300, and 400 kHz modes, collecting for short pulse, long pulse, and frequency modulated pulse within each frequency. Mosaics were created for each line, and the uncorrected histograms averaged to give a baseline dB value (Figure 31). A table was created, noting dB departures from baseline value for each vessel / frequency / pulse length (Table 6). A total spread of 4.5 decibels was observed: -1.8 dB to 2.7 dB. Most intra-vessel values were within 0.6 dB of each other, ranging from 0.3 to 1.2 dB. These values are inputted into unique vessel parameters for each vessel, frequency, and pulse length, applied when importing data to QPS FMGT for mosaic creation (Figure 32). We recommend tracking and limiting to only necessary frequency and pulse length settings during acquisition, so as to streamline application during post-processing.

Figure 31 - Detections on each object, normalized to soundings per meter, as measured with each vessel and each frequency.

Table 6 - Relative frequency and pulse length values for sonar bias
7 Data Workflow Integration

7.1 Test application of post processed correctors
Data from acceptance testing was processed through both QPS Qimera and CARIS HIPS. While the post processed correctors were not specifically tested, various Kongsberg multibeams using the same data records are in use throughout the NOAA fleet, and the results of both the HIPS and Qimera workflows were used in confirming proper overall functioning of the EM2040s post-processing workflow for this report. The GGK timing string was used in for the SIS position input, as GGK allows for ellipsoidal height separation, as opposed to the geoid height separation of a GGA.
7.2 Test data resolution and density
Sounding density data were extracted from the extinction line to take advantage of the change in depth. The maximum swath was used for all frequencies: the 200 kHz and 300 kHz modes collected data to 75° to each side while the 400 kHz mode collected data to 65° to each side. This impacts both the sound density and the ping rate. Figure 25 shows the density estimates for the EM2040, and Figure 26 shows ping rates. At the test speed of 7.9 knots, the EM2040 exceeds NOAA complete coverage specifications by a factor of 3 to 10 in all depths for all frequencies. This system exceeds the object detection density specifications by a factor of 3 to 5 in all depths for the 400 kHz frequency, but only at depths greater than 60 meters for all frequencies. Using the full 75° swath degrades the ability for 200 and 300 kHz to perform at object detection specifications at survey speed. At 7.9 knots, the 200 and 300 kHz frequencies failed to meet object detection specifications at depths shallower than 60 meters (Figure 33). Based on these results, we suggest restricting swath width to 65° while conducting object detection surveys. Data density is not a concern for complete coverage surveys when using full swath width, though accuracy remains degraded in the outer beams (Figure 34). Testing with Fairweather launches demonstrated that 6.5 knots satisfies the object detection coverage requirement at full swath [8]. If using a reduced swath width of 65 degrees, these systems should meet object detection specifications at survey speeds up to 10 knots.

![Data Density at 7.9 Knots](image)

*Figure 33 – Sounding density for launch 2802 as estimated from the extinction lines. Maximum swath width for 200 and 300 kHz: 75°, maximum swath width for 400 kHz: 65°. Note the logarithmic scales on both axes.*
7.3 Test total propagated uncertainty

Kongsberg produces real time uncertainty for the echo sounder component of the uncertainty model according to the method recommended by Ifremer [6]. These records can be ingested by CARIS to contribute toward the sonar portion of the Total Propagated Uncertainty (TPU).

This evaluation was conducted using ellipsoid referenced data collected over the reference surface. Uncertainty was calculated using Vessel as the uncertainty source for all values with the exception of Tide: tide was set to Static. Tide Measure was set to 0.05 meters to represent the ellipsoid height reference uncertainty, while 0.09 was used for Zoning to represent the VDatum uncertainty. In the Vessel file all waterline referenced uncertainties were set zero, such as heave and draft, because they are not used when a survey is conducted to the ellipsoid.

The overall gridded TPU was observed to be generally half of the IHO/NOAA permitted uncertainty, including the uncertainty contributions from ellipsoid height (5 cm $\pm 0.5$, nominally). The uncertainty contribution from the echo sounder is generally less than 3% of the total TPU. A plot for launch 2801 in 300 kHz mode is included in Figure 35.
7.4 Difference Surface
A reference surface was created for all boats and each frequency over the area commonly call the Shilshole Reference Surface. A previously utilized 1 meter reference surface from Rainier launch 2802 collected with a Reson 7125 in 400 kHz mode in 2008 was compared with 0.50 meter surfaces from acceptance work. These surfaces were referenced to the ellipsoid and reduced to Mean Lower Low Water (MLLW) using the VDatum separation for the location. The ellipsoid height was from the real time data (RTK) for all vessels. The real time data was referenced to ITRF2008 and had an offset from MLLW of 24.625 meters with an uncertainty of 0.097 meters.

We excluded the areas around the wrecks and features from the difference surface for this analysis (Table 7).
The Shilshole reference surface ranges in depth from 12 meters to 28 meters deep. For reference, the IHO Order 1 allowable uncertainties are included in Table 8.

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Table 8 – IHO Order 1 TVU, as calculated with \(a = 0.5\) and \(b = 0.013\)

To confirm the waterline reference an ERZT [7] solution was computed for the reference surface area using the Process > Compute > Separation Model function offered in CARIS HIPS. These data were gridded at 10 meters, differenced with the VDatum MLLW to the ellipsoid separation at this location, and the statistics recorded in Table 9. These bias terms are within the combined uncertainty of 0.15 meters for the waterline, dynamic draft, tides (TCARI), and VDatum, and indicate a satisfactory level of agreement for use with tidally reduced data.

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Table 9 - CARIS Separation Model differenced from VDatum separation (i.e. sum of all ERS and water level vertical control errors)

All modes tested showed a consistent negative bias (-0.17 ± 0.03 meters) against the reference data set. However, the vertical control for all launches was consistent between an ERS and water level approach (0.02 ± 0.04 meters, Table 9) suggesting that the observed bias was not from the vertical control of the
current launch data. We suspect that the bulk of this bias is in the reference data set. The standard deviation of the launch data relative to the reference set was small (0.02 ± 0.05 meters).

8 Concluding Summary

New Kongsberg EM2040s were installed on each of the four Rainier launches to update the capability of NOAA's Hydrographic fleet. The new multibeam echo sounders demonstrated performance that met or beat NOAA standards in their deployed configuration. While the noise levels for these boats appear to be high, especially in shallow water, the systems perform as specified by Kongsberg.

These tests utilized the recommended locations Sonar Acceptance process has been applied to launch multibeam echo sounders in Puget Sound. Products of this test include new locations for collecting baseline and calibration data for NOAA vessels in the future.

Acknowledgements

We would like to observe the importance of OMAO support for performing these tests and Kongsberg support for carrying out good installation and testing. We hope that these groups, Coast Survey, and other future users of Rainier data find value in the confirmation of proper installation and the collection of baseline information for these echo sounders.

9 References

10 Appendices

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### Vessel Offsets

**10.6.1 Launch 2801**

**Vessel:** NOAA Rainier Launch 2801  
**Date of Patch Test:** September 14, 2017

**Surveyor:**

**Offsets**

This spreadsheet takes the original surveyed offsets and both translates and rotates them into a new reference frame. Two methods of rotation are shown. One is valid for small angles and is included to aid in understanding the result. The "General Solution" section is generally applicable for all rotations.

Survey was originally done in gravity-level frame.

This sheet was adapted from a sheet created by S. Greenaway.

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### 10.6.2 Launch 2802

**Vessel:** NOAA Rainier Launch 2802  
**Date of Patch Test:** September 14, 2017

**Surveyor:**

This spreadsheet takes the original surveyed offsets and both translates and rotates them into a new reference frame. Two methods of rotation are shown. One is valid for small angles and is included to aid in understanding the result. The “General Solution” section is generally applicable for all rotations.

Survey was originally done in gravity-level frame.

This sheet was adapted from a sheet created by S. Greenaway.

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### 10.6.3 Launch 2803

#### Vessel: NOAA Rainier Launch 2803

**Date of Patch Test:** September 14, 2017

**Surveyor:**

**Offsets**

This spreadsheet takes the original surveyed offsets and both translates and rotates them into a new reference frame. Two methods of rotation are shown. One is valid for small angles and is included to aid in understanding the result. The "General Solution" section is generally applicable for all rotations.

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10.6.4 Launch 2804

Vessel: **NOAA Rainier Launch 2802**  
Date of Patch Test: **September 14, 2017**  
Surveyor:

### Offsets

This spreadsheet takes the original surveyed offsets and both translates and rotates them into a new reference frame. Two methods of rotation are shown. One is valid for small angles and is included to aid in understanding the result. The "General Solution" section is generally applicable for all rotations.

Survey was originally done in gravity-level frame.

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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>forward</td>
<td>starboard</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>TEST (just for checking the math)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>IMU</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Port GPS Antenna (Zepher II) TDC</td>
<td>-0.845</td>
<td>-0.645</td>
</tr>
<tr>
<td>Starboard GPS Antenna (Zepher II) T1</td>
<td>-0.844</td>
<td>0.713</td>
</tr>
<tr>
<td>Centerline Bow BM</td>
<td>3.430</td>
<td>0.013</td>
</tr>
<tr>
<td>Centerline Stern BM</td>
<td>-4.084</td>
<td>0.013</td>
</tr>
<tr>
<td>Centerline BM</td>
<td>-0.126</td>
<td>0.025</td>
</tr>
<tr>
<td>Port Side BM</td>
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<td>-1.438</td>
</tr>
<tr>
<td>Starboard Side BM</td>
<td>0.077</td>
<td>1.475</td>
</tr>
<tr>
<td>Keel BM Aft</td>
<td>-0.609</td>
<td>0.003</td>
</tr>
<tr>
<td>Keel BM Forward</td>
<td>0.413</td>
<td>0.009</td>
</tr>
<tr>
<td>KM EM2040 TX</td>
<td>0.094</td>
<td>0.198</td>
</tr>
<tr>
<td>KM EM2040 RX</td>
<td>-0.006</td>
<td>-0.107</td>
</tr>
<tr>
<td>Portside GPS Ant. Phase Center</td>
<td>-0.845</td>
<td>-0.645</td>
</tr>
<tr>
<td>Starboard GPS Ant. Phase Center</td>
<td>-0.844</td>
<td>0.713</td>
</tr>
<tr>
<td>Waterline</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
10.2 **CARIS HIPS Vessel File**

The HIPS Vessel File (HVF) acts as the reference frame when incorporating waterline and dynamic draft fields. All other reference frames are established in SIS and POS configuration. The HVF of launch 2801 is provided here for reference.

Vessel Name: 2801_EM2040
Vessel created: March 22, 2018

```xml
<?xml version="1.0"?>
<HIPSVesselConfig Version="2.0">
  <VesselShape>
    <PlanCoordinates>
      <Entry X="-1.500000" Y="-4.000000"/>
      <Entry X="1.500000" Y="-4.000000"/>
      <Entry X="1.500000" Y="3.000000"/>
      <Entry X="0.000000" Y="5.000000"/>
      <Entry X="-1.500000" Y="3.000000"/>
      <Entry X="-1.500000" Y="-4.000000"/>
    </PlanCoordinates>
    <ProfileCoordinates>
      <Entry Y="-4.000000" Z="0.600000"/>
      <Entry Y="-4.000000" Z="-0.600000"/>
      <Entry Y="3.000000" Z="-0.600000"/>
      <Entry Y="5.000000" Z="0.600000"/>
      <Entry Y="-4.000000" Z="0.600000"/>
    </ProfileCoordinates>
    <RP Length="4.000000" Width="1.500000" Height="0.500000"/>
  </VesselShape>
  <DepthSensor>
    <TimeStamp value="2017-257 00:00:00"/>
    <Latency value="0.000000"/>
    <SensorClass value="Swath"/>
    <TransducerEntries/>
  </DepthSensor>
</HIPSVesselConfig>
```
<Transducer Number="1" StartBeam="1" Model="em2040_300N">
    <Manufacturer value="Kongsberg"/>
    <Offsets X="0.000000" Y="0.000000" Z="0.000000" Latency="0.000000"/>
    <MountAngle Pitch="0.000000" Roll="0.000000" Azimuth="0.000000"/>
</Transducer>

<Transducer Number="2" StartBeam="1001" Model="Unknown">
    <Offsets X="0.000000" Y="0.000000" Z="0.000000" Latency="0.000000"/>
    <MountAngle Pitch="0.000000" Roll="0.000000" Azimuth="0.000000"/>
</Transducer>
</TransducerEntries>

<Comment value=""/>
</TimeStamp>
</DepthSensor>

<DepthSensor>
    <TimeStamp value="2015-129 00:00:00">
        <Comment value="HSL historic avg"/>
        <Latency value="0.000000"/>
        <ApplyFlag value="Yes"/>
        <DraftEntries>
            <Entry Speed="0.000000" Draft="0.000000"/>
            <Entry Speed="0.971922" Draft="-0.010000"/>
            <Entry Speed="1.943844" Draft="-0.010000"/>
            <Entry Speed="2.915767" Draft="0.000000"/>
            <Entry Speed="3.887689" Draft="0.020000"/>
            <Entry Speed="4.859611" Draft="0.030000"/>
            <Entry Speed="5.831533" Draft="0.050000"/>
            <Entry Speed="6.803456" Draft="0.050000"/>
            <Entry Speed="7.775378" Draft="0.050000"/>
            <Entry Speed="8.747300" Draft="0.030000"/>
            <Entry Speed="9.719222" Draft="0.000000"/>
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    </TimeStamp>
</DepthSensor>
<Entry Speed="10.691145" Draft="-0.050000"/>
<Entry Speed="11.663067" Draft="-0.100000"/>
<Entry Speed="12.634989" Draft="-0.140000"/>
<Entry Speed="13.606911" Draft="-0.200000"/>

</DraftEntries>
</TimeStamp>
</DraftSensor>

<GyroSensor>
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<Manufacturer value="(null)"/>
<Model value="(null)"/>
<SerialNumber value="(null)"/>
</TimeStamp>
</GyroSensor>

<HeaveSensor>
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<Manufacturer value="(null)"/>
<Model value="(null)"/>
<SerialNumber value="(null)"/>
</TimeStamp>
</HeaveSensor>

<NavSensor>
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<Latency value="0.000000"/>
<Ellipse value="NA83"/>
<Offsets X="0.000000" Y="0.000000" Z="0.000000"/>
<Comment value="new launch (RP=EM2040TX)"/>
<Manufacturer value="Applanix"/>
<Model value="POS/MV 320 V5"/>
<SerialNumber value=""/>
</TimeStamp>
</NavSensor>

<PitchSensor>
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<ApplyFlag value="No"/>
<Offsets Pitch="0.000000"/>
<Comment value="(null)"/>
<Manufacturer value="(null)"/>
<Model value="(null)"/>
<SerialNumber value="(null)"/>
</TimeStamp>
</PitchSensor>

<RollSensor>
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<ApplyFlag value="No"/>
<Offsets Roll="0.000000"/>
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<Manufacturer value="(null)"/>
<Model value="(null)"/>
<SerialNumber value="(null)"/>
</TimeStamp>
</RollSensor>
</RollSensor>

<WaterlineHeight>

<TimeStamp value="2017-257 00:00:00">
  <Latency value="0.000000"/>
  <WaterLine value="-0.631000"/>
  <ApplyFlag value="No"/>
  <StdDev Waterline="0.030000"/>
  <Comment value="(null)"/>
</TimeStamp>
</WaterlineHeight>

<TPEConfiguration>

<TimeStamp value="2017-257 00:00:00">
  <Comment value="new instal"/>
  <Latency value="0.000000"/>
  <Offsets>
    <MRUtoTransducer X="0.203000" Y="0.136000" Z="0.535000" X2="-0.102000" Y2="0.036000" Z2="0.519000"/>
    <NavigationToTransducer X="0.203000" Y="0.136000" Z="0.535000" X2="-0.102000" Y2="0.036000" Z2="0.519000"/>
    <Transducer Roll="0.000000" Roll2="0.000000"/>
    <Navigation Latency="0.000000"/>
  </Offsets>
  <StandardDeviation>
    <Motion Gyro="0.020000" HeavePercAmplitude="5.000000" Heave="0.050000" Roll="0.020000" Pitch="0.020000" PitchStablized="0.000000"/>
    <Position Navigation="1.000000"/>
    <Timing Transducer="0.005000" Navigation="0.005000" Gyro="0.005000" Heave="0.005000" Pitch="0.005000" Roll="0.005000"/>
    <SoundVelocity Measured="0.000000" Surface="0.000000"/>
    <Tide Measured="0.000000" Zoning="0.000000"/>
  </StandardDeviation>
  <Offsets X="0.010000" Y="0.010000" Z="0.010000"/>
  <MRUAlignment Gyro="0.200000" Pitch="0.100000" Roll="0.100000"/>
<Vessel Speed="0.080000" Loading="0.025000" Draft="0.020000" DeltaDraft="0.010000">
  <StDevComment value="(null)"/>
</Vessel>
</StandardDeviation>
</TimeStamp>
</TPEConfiguration>
<SVPSensor>
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    <Latency value="0.000000"/>
    <DualHead value="Yes"/>
    <Offsets X="0.000000" Y="0.000000" Z="0.000000" X2="-0.305000" Y2="-0.100000" Z2="-0.016000"/>
    <MountAngle Pitch="0.000000" Roll="0.000000" Azimuth="0.000000" Pitch2="0.000000" Roll2="0.000000" Azimuth2="0.000000"/>
  </TimeStamp>
</SVPSensor>
</HIPSVesselConfig>
10.3 Configuration Screen Grabs
The integration of wiring, IP address and ports, as well as data records was intended to be uniform across all launches. A single set of configuration screen grabs from launch 2801 are provided here for reference.

10.6.5 SIS
### Installation Parameters

#### Positioning System Settings
- Time to use:
  - Diagram
  - System
- Enable position update correction
- Position delay (sec):
- Return:
- Log all heights:
  - Enable
  - Pos. equal indicators for height correction

#### Altitude Sensor Settings
- Altitude sensor:
  - POS/LAD
- Altitude reference plane:
  - Horizontal (X)
- Rotation (POS/LAD)
- Altitude delay (sec): 0

#### Active Sensors
- Position:
  - POS/LAD
- Altitude:
  - COM2
- Heading:
  - COM2
- Velocity:
  - UPS

### Sensor Settings

#### Location Offset (m)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Forward (X)</th>
<th>Starboard (Y)</th>
<th>Downward (Z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POS1, COM1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>POS2, COM2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>POS, COM/UD/FX</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>OI/KI/TF Transducer</td>
<td>1.1</td>
<td>-9.205</td>
<td>-0.026</td>
</tr>
<tr>
<td>TX Transducer</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>RX Transducer</td>
<td>-9.205</td>
<td>-9.205</td>
<td>-0.026</td>
</tr>
<tr>
<td>Attitude1, COM2/UDPS</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Attitude2, COM2/UDPS</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Waterline</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Depth Sensor</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
10.4 Accuracy Testing
Launch 2801

Figure 25 - Launch 2801 200 kHz, short CW (left), long CW (middle), FM (right)

Figure 26 - Launch 2801 300 kHz, short CW (left), long CW (middle), FM (right)

Figure 27 - Launch 2801 400 kHz Short CW (left), long CW (right)
Figure 28 - Launch 2802 200 kHz, short CW (left), long CW (middle), FM (right)

Figure 29 – Launch 2802 300 kHz, short CW (left), long CW (middle), FM (right)

Figure 30 - Launch 2802 400 kHz Short CW (left), long CW (right)
Launch 2803

Figure 31 - Launch 2803 200 kHz, short CW (left), long CW (middle), FM (right)

Figure 32 - Launch 2803 300 kHz, short CW (left), long CW (middle), FM (right)

Figure 33 - Launch 2803 400 kHz Short CW (left), long CW (right)
Launch 2804

Figure 34 - Launch 2804 200 kHz, short CW (left), long CW (middle), FM (right)

Figure 35 - Launch 2804 300 kHz, short CW (left), long CW (middle), FM (right)

Figure 36 - Launch 2804 400 kHz Short CW (left), long CW (right)
10.5 Noise Testing

Launch 2801 Deep Noise

Figure 37 - Launch 2801 BIST RX Noise (left) and RX Noise Spectrum (right) in deep water.

Figure 38 - Launch 2801 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in deep water.

Figure 39 - Launch 2801 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in deep water.
Launch 2801 Shallow Noise

Figure 40 - Launch 2801 BIST RX Noise (left) and RX Noise Spectrum (right) in shallow water.

Figure 41 - Launch 2801 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in shallow water.

Figure 42 - Launch 2801 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in shallow water.
Launch 2802 Deep Noise

Figure 43 - Launch 2802 BIST RX Noise (left) and RX Noise Spectrum (right) in deep water.

Figure 44 - Launch 2802 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in deep water.

Figure 45 - Launch 2802 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in deep water.
Launch 2802 Shallow Noise

Figure 46 - Launch 2802 BIST RX Noise (left) and RX Noise Spectrum (right) in shallow water.

Figure 47 - Launch 2802 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in shallow water.

Figure 48 - Launch 2802 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in shallow water.
Launch 2803 Deep Noise

Figure 49 - Launch 2803 BIST RX Noise (left) and RX Noise Spectrum (right) in deep water.

Figure 50 - Launch 2803 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in deep water.

Figure 51 - Launch 2803 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in deep water.
Launch 2803 Shallow Noise

Figure 52 - Launch 2803 BIST RX Noise (left) and RX Noise Spectrum (right) in shallow water.

Figure 47 - Launch 2803 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in shallow water.

Figure 51 - Launch 2803 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in deep water.
Launch 2804 Deep Noise

Figure 53 - Launch 2804 BIST RX Noise (left) and RX Noise Spectrum (right) in deep water.

Figure 54 - Launch 2804 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in deep water.

Figure 55 - Launch 2804 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in deep water.
Launch 2804 Shallow Noise

Figure 56 - Launch 2804 BIST RX Noise (left) and RX Noise Spectrum (right) in shallow water.

Figure 57 - Launch 2804 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam in shallow water.

Figure 58 - Launch 2804 200 kHz (left), 300 kHz (center) and 400 kHz (right) passive water column noise averaged by beam and by RPM in shallow water.
10.6 Extinction Tests

Figure 62 - Launch 2801 extinction test for all frequencies

Figure 63 - Launch 2802 extinction test for all frequencies
Figure 64 - Launch 2803 extinction test for all frequencies

Figure 65 - Launch 2804 extinction test for all frequencies