

MARITIME ROBOTICS

HYDROGRAPHIC CAPABILITIES TEST

Suitability Assessment of Maritime Robotics USV for Hydrographic Charting

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This report documents the results and findings from sea trials performed in Trondheim Norway of the installed Hydrographic Sensor Suite aboard the Maritime Robotics Unmanned Surface Vessel in February, 2014.

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1. INTRODUCTION

Testing of the new Unmanned Survey Vessel, Mariner 560 from Maritime Robotics, was tested for capability for use as a hydrographic survey platform in Trondheim, Norway in February, 2014. Advantages of remotely operated yet visible unmanned survey platforms bring advantages towards safety of personnel, equipment and efficiency all resulting in potential financial savings.

The vessel was outfitted with a high resolution multibeam system integrated with a complete GNSS-INS positioning and attitude navigation package.

2. MARINER 560

The Maritime Robotics Mariner 560 Unmanned Surface Vessel (USV) is a multipurpose unmanned vehicle with hull made of durable and light-weight polyethylene with a design that is very stable, unsinkable and maintenance free. The propulsion system is comprised of a diesel inboard Volvo Penta D3 and a Hamilton 241 water-jet pump. The complete craft may be shipped inexpensively to project sites using a standard 20ft container.



2.1.Hull Design & Construction

The vessel is designed and manufactured by PolarCirkel. Hull material is a high density polyethylene which is lighter than water. The material withstands hard scrapes over rocks with little damage. The vessel resembles a RHIB where the pontoons are filled with expanded polystyrene making them virtually unsinkable. They are easily operated in many of the worst conditions such as shallow waters, very rough conditions, arctic ice regions, temperatures from -40°C to +55°C

2.2.Propulsion Mechanics

Locating genuine dealer facilities for parts or service of a vessel's propulsion system is critical to reduce project risk should help be required. The Mariner 560 incorporates a Volvo-Penta D3, one of the most widely known marine engine manufacturers, and a Hamilton 241 jet pump, the most recognized water-jet pump globally.



The 250 liter (66 US Gallons) diesel tank provides for at least 50 hours of continuous use at typical survey speeds.

The jet pump allows for excellent maneuverability and operation in very shallow waters where a propeller would not last long. For difficult areas of for docking in high winds, a bow thruster is provided.

2.3.Sensor Payload

Located at the midsection, a >1 cubic meter fully enclosed payload area offers environmental protection for electronics hardware. The moonpool is located here with an option for a remotely controlled raising/lowering ram to al-

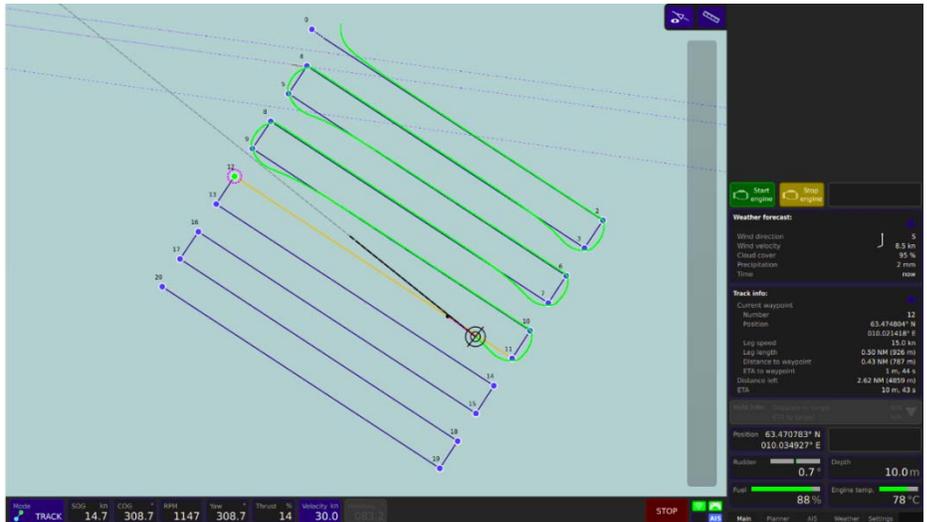
low for high speed (>30knots) transits between surveys. The sonar may optionally be faired into the hull. Aside from multibeam and singlebeam sonar systems, additional sensors might include ADCP, automatic sound speed profilers, radar systems, LIDAR, etc. which further expand the vehicles capabilities.

2.4. Vehicle Control System (VCS)

The VCS is a software-based guidance control system that may be operated from a typical laptop. This user interface provides spatial understanding of the vehicles location with respect to various layers that include ECDIS, NMEA Navigation data, AIS feeds, radar, camera video and thermal-imaging video. Engine data (such as RPM, fuel level, temperature, battery voltage) is monitored on the VCS together with navigation information (such as speed and course).

The USV Operator may seamlessly shift between:

- Manual control of the vehicle using either a remote control console to guide the vehicle visually or via the VCS to guide it with respect to data shown on the multi-layered display using a joystick or keyboard/mouse.
- Automatic control to guide the vehicle along pre-set run-lines in the VCS.



3. BATHYMETRIC PAYLOAD USED FOR TEST

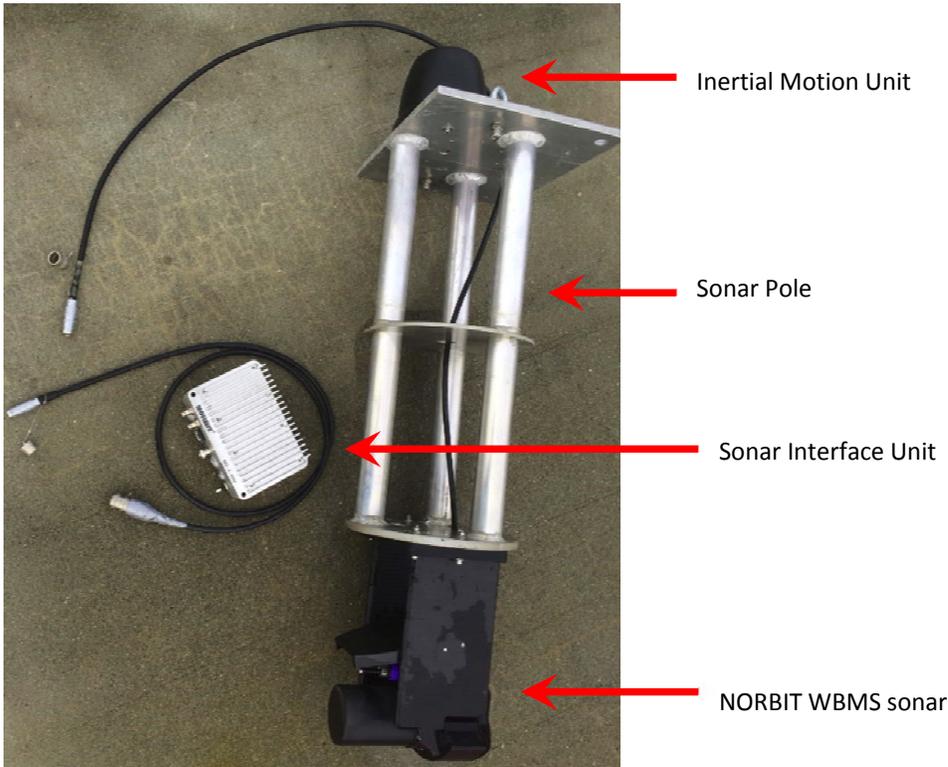
The vehicle was fitted with a NORBIT Integrated Wideband Multibeam Sonar, iWBMS. This includes the sonar, an inertial motion sensor, a surface sound sensor and two GNSS antennas.

3.1. NORBIT iWBMS

A compact curved array multibeam sonar that is integrated with a surface sound speed sensor and an Inertial Navigation System that utilizes GNSS signals together with an Inertial Motion Unit. The sonar transmits up to a 78 kHz bandwidth nominally centered at 400 kHz to receive a wide swath of 256 equidistant bottom detections. The position, heading and attitude of the INS is further bettered with GNSS Real Time Kinematics correction signals to better than 2-3cm's.



3.2. Installation:



Primary GNSS Antenna

Secondary GNSS Antenna



4. SEAFLOOR MAPPING TESTS

4.1. Testing Overview

The purpose of the test was to determine the suitability of the USV as a platform for hydrographic surveys. For this, the vessel was brought through the typical procedures for sensor calibrations followed by a survey of a relatively challenging shoreline area. The survey was made more challenging due to the temporally and spatially large changes to water sound speed from the confluence of a nearby river into Trondhiemsfjord

4.2. Installation & Sensor Lever Arm Offsets

As the underside of the vessel hull resembles that of a RHIB the moonpool is ideally situated at the vessel port/starboard centerline. The pontoons build the strength/rigidity of the craft as opposed to a singular keel backbone. The payload moonpool exists at this vessel port/starboard centerline and forward of the vessel COR. The placement or size of the moonpool could be changed without major upset to the hull design.

The sonar was mounted nearly 1meter below the water surface, a plane that approximates the bottom level surface of the payload compartment. Due to timing, a comprehensive offset survey could not be performed nor the precise offsets to the water level made; the survey is therefore relative in accuracy. The IMU reference was utilized as the reference which is likely some 10-15cm high. Further, a squat & settlement test was not possible due to the sporadic RTK GNSS correction signal. Instead, the automatic calibration routines of the iWBMS were utilized to determine the antenna offsets and showed high repeatability.

The table below shows the manually measured offsets along with the iWBMS automatic calibration measurements which are noted with an asterisk (*).

Sensor/Node	+Fwd (meters)	+Stbd (meters)	+Dwn (meters)
Central Ref Point	0.000	0.0000	0.000
NORBIT Sonar Ref	-0.019	0.000	0.997
INS Ref Pt	0.000	0.000	0.000
*IMU→Ant1 (Jan30)	2.640	-0.001	-0.871
*IMU→Ant1 (Jan31)	2.651	0.002	-0.872
*IMU→Ant1 (Feb1)	2.640	0.005	-0.886
*Ant1-Ant2 (Jan30)	-4.759	0.043	-0.079
* Ant1-Ant2 (Jan31)	-4.761	0.042	-0.082
* Ant1-Ant2 (Feb1)	-4.758	0.041	-0.074

Each day, the primary antenna offset calibration was carried out followed by a secondary antenna calibration. This is a process that utilizes the gyro information and the GNSS positions to determine the offsets between each as the vessel is brought to very tight circles/figure-of-eights with the availability of an RTK GNSS correction signal. Despite the sonar being removed and replaced by a different system at end of the 30 January – the offset measurements were highly repeatable. This indicates strong agreement on sensor offset measurements and repeatability of sensor position placement even through removal/replacement.

4.3. Vessel Control During Test

A BETA version of the VCS was created for this test and allowed for the on-line surveyor to setup a line plan over a chart or aerial TIFF image layer for the vessel to automatically follow. The line planning capabilities of the VCS were intuitive and provides sufficient options to create parallel survey lines in any orientation on-the-fly. Plans call for automatic survey-line import via whatever data acquisition software package is employed in addition to radial survey lines planning.

In areas requiring manual control of the craft, the on-line surveyor may manually navigate the craft using a shoulder slung, weather resistant remote control console and the vessel then navigated by the surveyor from the back deck of the support vessel where full visibility of the USV would be maintained. Or, the vessel may be manually controlled with a gaming joy-stick connected to the WiFi connected laptop running the VCS and the location of the craft is navigated from the screen with reference to the background layers utilized by the surveyor.

The advantages of being able to quickly take the vessel off autopilot are principally for safety purposes but may also be utilized, as was the case during this test, for detailing bathymetry along shorelines and tricky built environments. With the addition of a video camera feed, the operator could navigate from within the comforts of the remote support vessel though this would require minimal latency on the video feed.

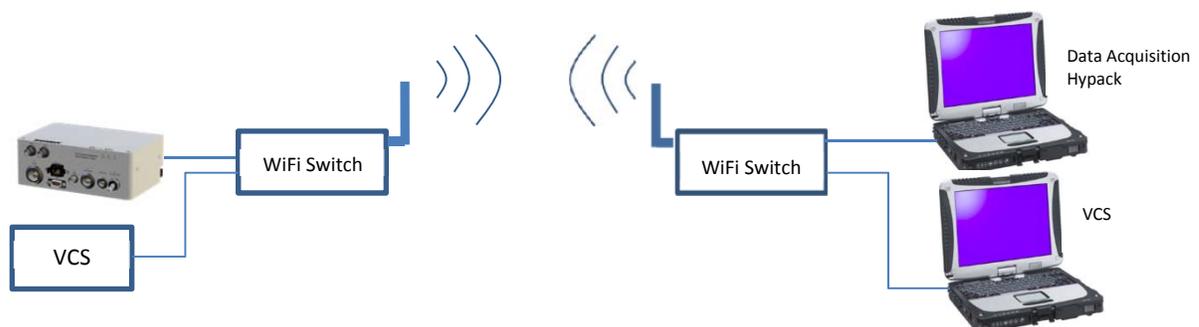
To lend towards further safety, the vessel outputs an AIS message and the VCS displays all received AIS vessel positions and navigation data to the user interface plan view. If a vessel is nearing the safety boundary around the USV, an alarm is sounded. This requires a separate AIS receiver or internet access.

4.4. Data Acquisition

All bathymetric data collection was acquired wirelessly from the survey support craft. Wireless communication was performed by streaming data directly from the USV over a specialized extended-range WiFi connection to the remote support vessel. This was accomplished using two methods where the latter became the most reliable:

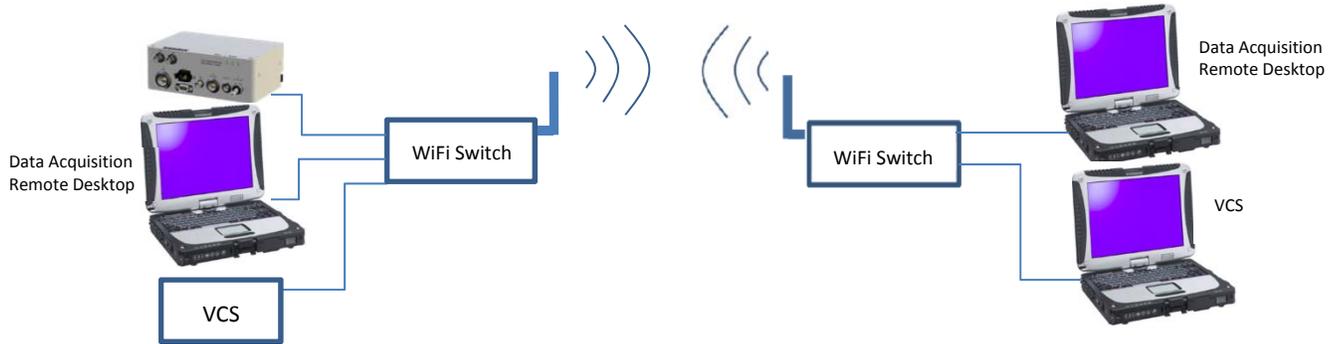
1. Support Vessel Acquisition Laptop:

Raw data records fed wirelessly to survey support launch for control and acquisition. Weak signals beyond a couple kilometers resulted in data dropouts. An option was discussed that could extend this range.



2. Support Vessel Remote Display Laptop:

Raw data records are logged directly to survey software on acquisition laptop onboard the USV which is connected to a WiFi switch and picked up via a typical Windows Remote Desktop Connection on the support vessel. Even if WiFi connection to support vessel is temporarily interrupted, no loss to data occurs. Meanwhile, near real-time control of the payload is tolerated for such things as sonar tuning, calibrations, target placements, etc.



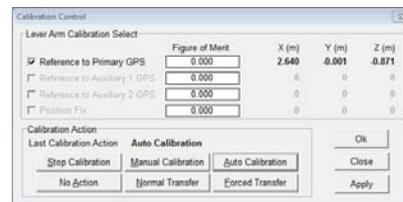
Some outages occurred during the use of the first connection/recording scenario which resulted in data gaps. The second acquisition method provided no data gaps due to connection outages even if the support vessel was a kilometer away.

4.5. Calibrations

Calibrations of the kit were carried out with relative ease. The bathymetric payload aboard the Mariner 560 was calibrated remotely from the support vessel by commands sent over WiFi. First the INS calibrations were carried out and applied and then the sonar angular offsets were calibrated and applied.

4.5.1. GNSS-INS Positioning Calibration

Once radio RTK GNSS corrections were available, calibrations of the IMU to primary antenna and then primary to secondary antenna were automatically measured and later compared (see offsets table further up). Tight lever arm distances between the IMU and the GNSS antennas, proximity of the IMU and sonar to the center of rotation and a 4 ¾ meter antenna baseline allowed for accurate and speedy automated calibrations.

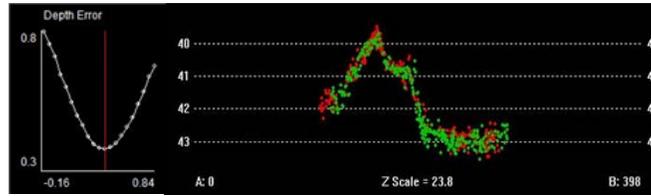


The multibeam alignment calibrations were measured twice and again, strong agreements were had.

4.5.2. Multibeam Alignment Calibration – Roll

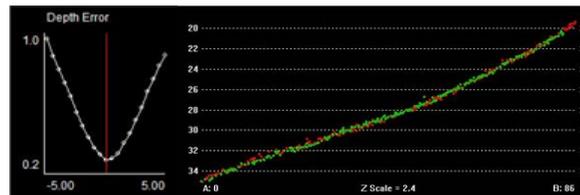
The roll test is comprised of a single survey line run in reciprocal directions over the same area of generally flat seafloor bathymetry. Generally flat bathymetry was difficult to find for this survey site. The results determine the alignment offset of the sonar with respect to the motion sensor fixed to the vessel. An error in the roll would, for one swathe, pivot the measured values of about the nadir depth for one survey line while the second

survey line would also be pivoted but in the opposite direction resulting in a profile slice through the data that resembles an “X”. The roll value obtained was 0.39°



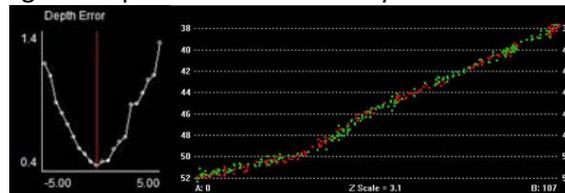
4.5.3. Multibeam Alignment Calibration – Pitch

Pitch alignment tests the multibeam sonar’s installation alignment and is obtained from running a single survey line in reciprocal directions over a bathymetric slope. An incorrect pitch values would have for one survey line the depths measured too shallow and for the other survey line, the measured depths would be too deep resulting in two depths for every point along the slope. The pitch value obtained from these tests was -2.0°



4.5.4. Multibeam Alignment Calibration – Yaw

Heading misalignment of the sonar with respect to the vessel/heading sensor is calibrated from data obtained from two survey lines run parallel up a slope. An incorrect multibeam sonar yaw value would displace the measured bottoms of one line above the real bottom and for the second line below the real bottom resulting in two depths for every point along the slope. A final measured yaw value was -0.5°

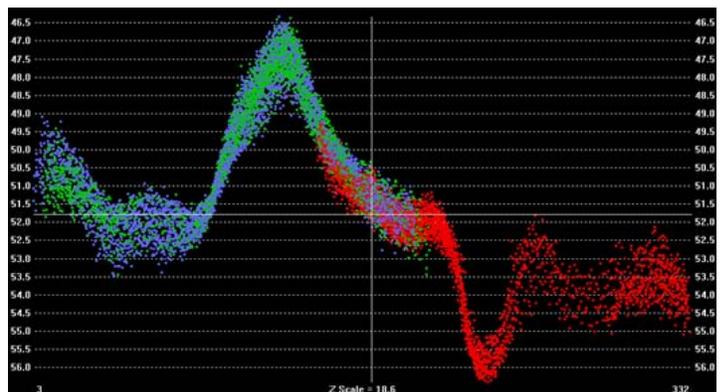


4.5.5. Final Patch Test Results

Various slices through the data are taken following the determination and implementation of a set of sonar mounting angles to verify that the data is correctly calibrated. Below shows such a profile in a fairly dynamic bathymetric location.

The final values obtained are tabulated below:

Component	Angular Offset
Roll	0.39°
Pitch	-2.0°
Yaw	-0.5°



4.6. Bathymetric survey 1 – Difficult Shoreline Mapping

A challenging site was utilized to test the USV’s capabilities for coastal charting. The Ilsvika Bay has relatively tight contours (steep slopes) with a shoreline comprised of shoaling beaches, rocky outcrops, random pilings, piers, jetty’s, large buoys and moored vessels.

To test the USV in this area, a line plan was created generally parallel to the contours visible on the chart. These were created into two distinct sets as the contours curved around the south portion of the bay. Autopilot mode was initiated on the VCS and the Mariner 560 proceeded to sound the region from about 150m water depth towards the shallows. Once the vessel was inside a 20m depth contour, the survey line spacing was decreased such that the vessel would always be inside a previously surveyed area to avoid grounding risk. Depths were monitored by the watchful eye of the online surveyor. This area resulted in a 100% overlap condition. When the depth decreased to less than 10m or the horizontal distance to an obstruction was less than about 50m then the vessel was taken offline from VCS autopilot control and operated manually via visual navigation with the Remote Control Console.

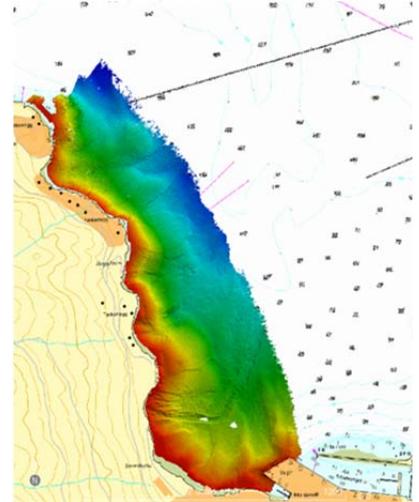
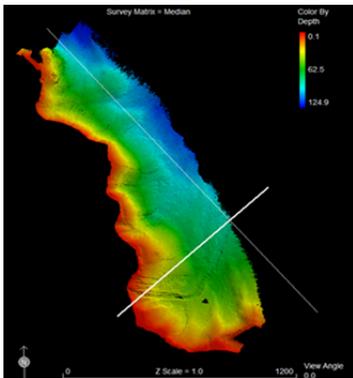
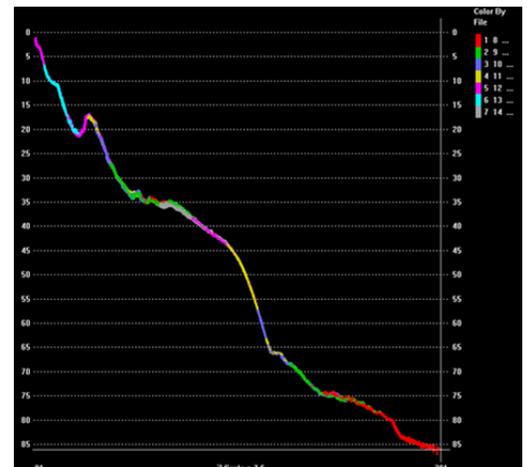


Figure 1 NEED TO REDO THIS IMAGE WITH CARIS



The USV was easily maneuvered around pilings, jetties and buoys using the Remote Control Console. As the complete spatial awareness was had by the remote operator, it could be said that this method of shoreline mapping carries less risk to equipment and certainly for personnel if operating in surf zone environments.

This survey was conducted with all acquisition occurring on the support vessel laptop (utilizing raw data records over WiFi). At times, the support vessel was about 1km away and this resulted in data gaps from lost WiFi connections. Consequently, this missed data becomes non-recoverable. If the support vessel is required to be more than 1km from the USV then a higher powered radio link is required. Alternatively, Windows Remote Desktop Connection is possible as was used for the second test survey.



4.7. Bathymetric Survey 2 – General Hydrographic Survey

As more time was available, another survey was conducted to west of Munkholmen Island. Again, survey lines were setup in the VCS and the Mariner 560 was brought into Autopilot mode and carried out the survey uninterrupted. All data was acquired onto a laptop situated in the dry payload compartment with control and online QA utilizing the remote desktop approach.



This configuration proved more stable both in terms of seamless data acquisition as well as control of the survey sensors. Survey lines were spaced according to anticipated water depth (as determined from a navigation chart).

During this general charting survey, a distinct feature was detected at 58m – 65m water depth.

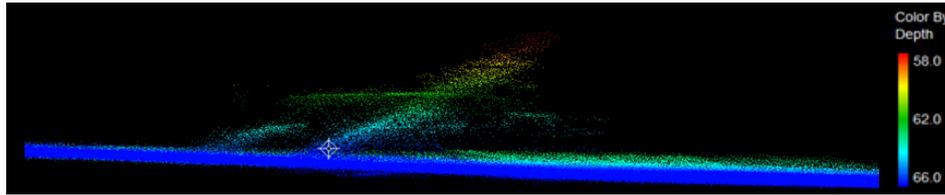
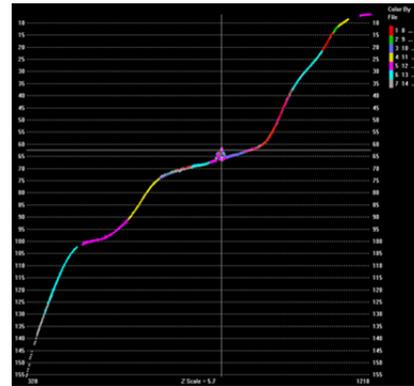
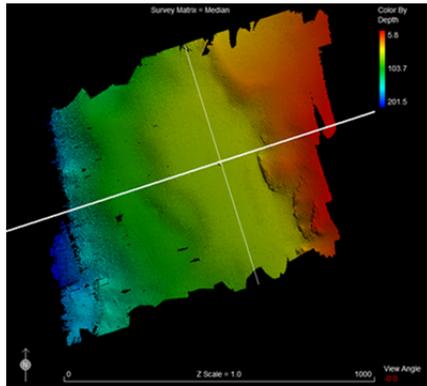
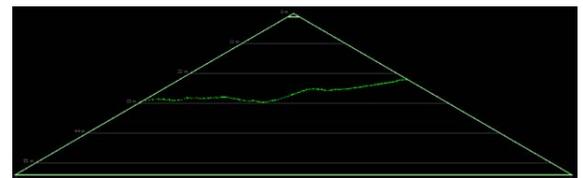
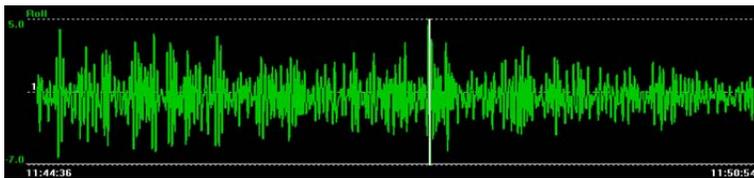


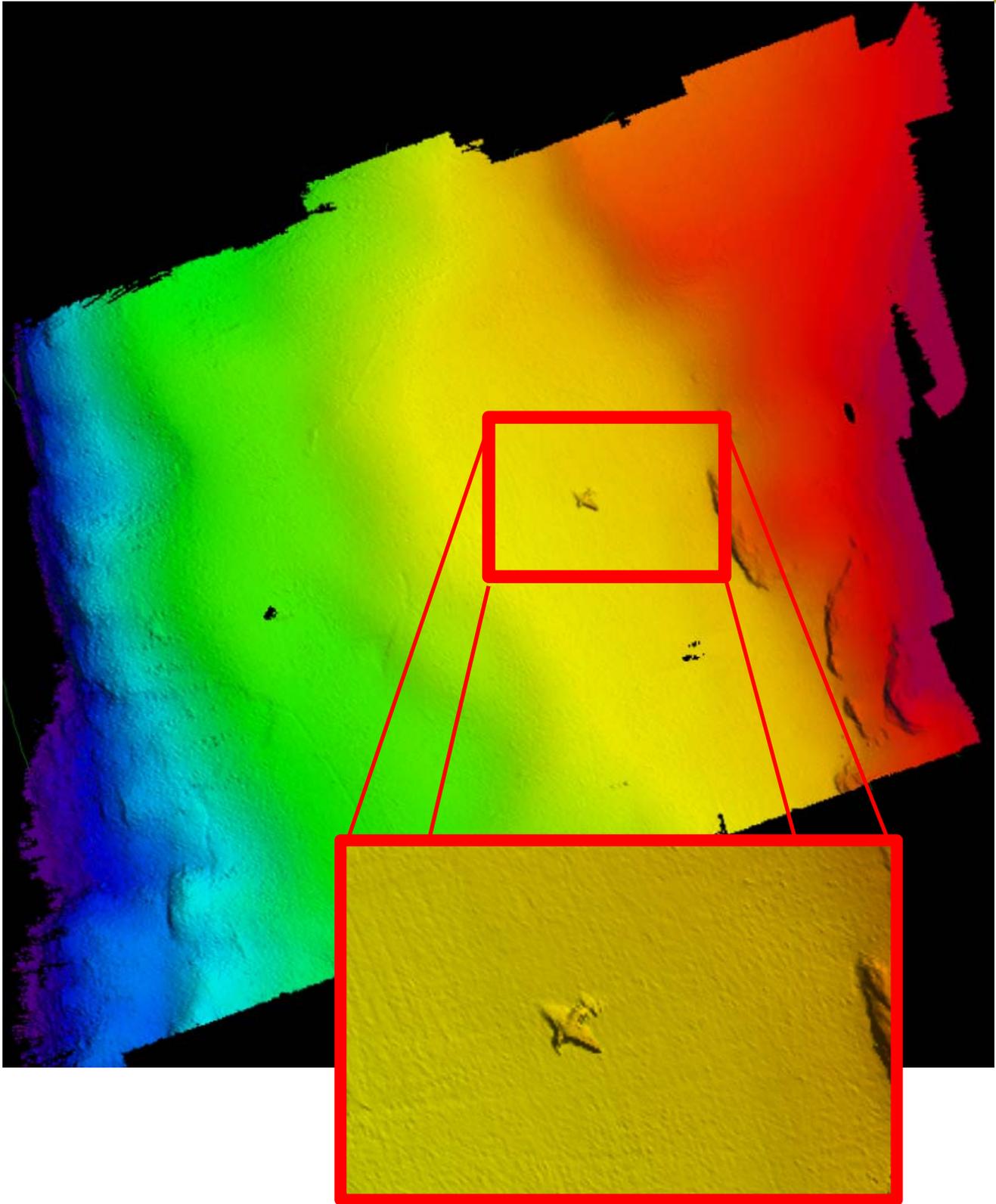
Figure 2: Airplane - Port wing buried into seafloor – Depths in meters



Weather conditions deteriorated again during this survey. While the support vessel was rolling some +/-15degrees, the USV experienced much less dynamics due to the low center of gravity. This is of particular interest as some USV critics have a perception that a lightweight 5.6m vessel would experience worse motion than a larger heavier vessel. However, as nearly no superstructure is required to support people (roof, additional navigation & safety gear, heaters, etc.) roll momentum is not contributed to. While the USV will, however, have higher frequency dynamics than a larger and heavier vessel this may be compensated for with a high update rate IMU located at or very near the sonar head as was the case for the USV integration.



A higher resolution image of the plane area appears on the following page. This image was created utilizing CARIS HIPS/SIPS processing software, a standard processing software utilized by Hydrographic Offices.



5. USV / IWBMS HYDROGRAPHIC PERFORMANCE

5.1. Accuracy

An absolute or relative accuracy assessment was not possible during these trials due to weather conditions and inability to locate a relatively flat bottom with less than 5° slopes. Nevertheless, it could be seen that the data does match well from line to line therefore little difference from conventional survey platforms is expected.

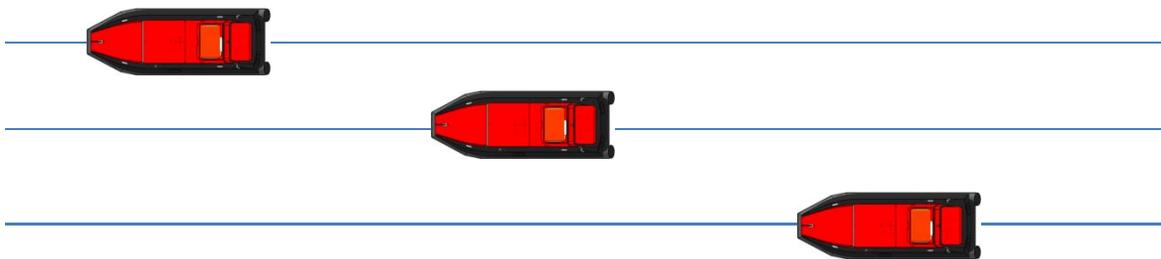
5.2. Efficiency

This trial was not conducted to test the efficiency of the USV. Yes, the opportunities for efficiency gain are numerous and rather exciting from a charting standpoint. During the trials, the support vessel was always made to stand-off the USV within a 1km distance. It was possible to acquire sound speed profiles at various locations whilst the USV continued to acquire bathymetric data. Also, the vessel operator for the mother vessel was able to contribute to the survey testing as continuous navigation was not required.

It is easily envisioned that large efficiency gains could be had if both the USV and the support vessel were both actively mapping the seafloor. The same number of personnel would be required for a single hydrographic survey vessel and yet efficiency would be nearly doubled.

One example of how this could be performed is that the support/survey vessel would ahead of the USV. The USV would automatically receive line steering instructions to ensure adequate survey coverage/overlap per the survey specifications. Alternatively, preset line plans would simplify the operation and the USV could always be made to operate ahead of the support/survey vessel on a parallel survey line. This allows for the crew to always maintain a watchful eye on the USV.

Taking this further, it could be possible to setup multiple USV's for swarm mapping of large areas quickly.



6. CONCLUSION

The Mariner 560 offers an exciting new multi-purpose platform to Hydrographic survey groups. While the vessel is rugged, lightweight, shippable (inside standard 20ft container), and easy to maintain it also provides large payload space for bathymetric data collection. The low center of gravity coupled with the safety of RHIB-like port and starboard pontoons contributes to stability that, arguably, exceeds that of a typical survey launch. Simple operation allow for easy master / slave operation with a dual purpose survey / support vessel for increased efficiencies This concept lends itself to futher upgradeability for multi-USV swarm mapping capabilities.