Integration and Operation of DriX-12 Aboard NOAA Ship Thomas Jefferson

Val Schmidt*, Rob Downs**, John Doroba**, LT Michelle Levano***

* e: vschmidt@ccom.unh.edu Center for Coastal and Ocean Mapping, University of New Hampshire
** e: rob.downs@noaa.gov john.doruba@noaa.gov Coast Survey Development Lab, Office of Coast Survey, NOAA
*** e: michelle.levano@noaa.gov NOAA Ship Thomas Jefferson

ABSTRACT:

In the summer of 2023, through funding provided by NOAA's Uncrewed Systems (UxS) Operations Center within the Office of Marine Operations, NOAA acquired a DriX uncrewed surface vehicle (USV) (Exail Inc.). The project is a collaborative effort by NOAA's Office of Coast Survey and NOAA Fisheries to operationalize the use of uncrewed systems to improve the efficiency of acoustic surveys from NOAA's ships. Sea Acceptance Testing of the vehicle was performed in collaboration with the University of New Hampshire's Center for Coastal and Ocean Mapping (CCOM) in August, 2022. Initial deployment and training of personnel aboard the NOAA Ship *Thomas Jefferson* occurred in early September. Afterward, two weeks of production survey operations were performed with DriX-12 as part-and-parcel of the ship's routine operations. Lessons learned during initial sea acceptance, shipboard integration, personnel training and staffing, and deployment and recovery will be discussed. An evaluation of survey operations in conjunction with the ship and DriX-12 data will also be provided.

INTRODUCTION:

In summer of 2022, through funding provided by the NOAA's Uncrewed Systems (UxS) Operations Center within the Office of Marine and Aviation Operations (OMAO), NOAA acquired a DriX-12 Uncrewed Surface Vehicle (USV) (Exail Inc.) to provide an operational platform for marine science. The project is a collaborative effort between NOAA's Office of Coast Survey (Rob Downs and CDR Damian Manda), NOAA Fisheries (Alex de Robertis and Michael Gallagher) with collaborators within OMAO (Don Jones and Sandra Parker-Stetter) and at University of New Hampshire's Center for Coastal and Ocean Mapping (Larry Mayer and Val Schmidt) to operationalize the use of uncrewed systems to improve the efficiency of their respective missions.

DRIX-12

The DriX USV is a 7.7 m LOA, 0.8 m wide, un-crewed and remotely operated USV whose hull and subsurface gondola were designed for acoustic survey work. The vehicle is powered with a 38 Hp diesel engine providing over 2 KW of electrical power for scientific payloads. The hull's narrow beam and wave piercing bow provide unusual speed and endurance for a vehicle of its size, achieving more than 12 knots maximum speed and an estimated 3-5 days of 24-hour endurance at 7 knots. These features allow the DriX to survey in tandem with a much larger vessel whose survey speeds usually greatly exceed that of a USV of this size. The gondola, some 2 m below the surface, provides stability to the vehicle, exhibiting relatively little roll or pitch relative to other vessels in similar sea states. In addition, the gondola provides an acoustically quiet location for sonars, largely protected from bubbles entrained near the surface. An evaluation of survey operations conducted by CCOM of DriX-5 in 2018 showed statistically undistinguishable results from seafloor surveys conducted at 8 knots, 10 knots and 12 knots.

The vehicle's telemetry systems include Wifi and a Kongsberg Marine Broadband Radio (MBR) for line-of-sight (LOS) communications, and both Iridium Short Burst Data (SBD) and Thales Certus Iridium systems for over the horizon (OTH) communications. For LOS systems, Wifi provides a high bandwidth low latency link for moving large data files and automated docking routines which require rapid transmission of position updates. The MBR provides lower bandwidth (up to ~15 Mbps) and longer latency links, but with much extended range, often exceeding 15 km compared to < 5 km for Wifi (atmospheric conditions dependent). With some tuning, five video streams, marine radar and a Remote Desktop Session can be maintained over an MBR link during survey operations.

For OTH communications the Iridium SBD system, which sends Twitter-length messages, provides basic position and critical system telemetry, plus the ability to start and stop a mission and to execute simple missions. SBD transmissions can take as much as 10 minutes to complete so operation in this mode is limited to low risk or emergency operation. The Certus Iridium provides a ~350 kbps link allowing full operation of the vehicle via satellite from an operator station ashore, connected to a cloud-hosted service. Position, critical system data, radar overlay and tracked targets are provided continuously during OTH operations via Certus. Missions are instantly executed, and camera and payload displays can be queried for still-shot updates.

In addition to these data telemetry systems, the DriX-12 also contains an embedded VHF radio and external microphone Transmissions received by the DriX are played for an operator at the operator station in near real time. A mic with push-to-talk capability and software running on the operator's PC provide the ability to send audio to the DriX for VHF transmission.

The DriX sensor suite includes an Automatic Identification Service (AIS) receiver, Simrad/Lowrance Halo20+ Marine Radar, Ouster Lidar, Infra-Red camera, and five color cameras providing 360-degrees of coverage. The DriX Obstacle Avoidance System (OAS) detects and tracks targets within 300 m using the platforms AIS, radar, lidar and the IR camera data, presenting these to operators and, if enabled, deviating from the intended path automatically to avoid them. The OAS system operates at relatively short range and therefore acts as a collision avoidance system rather than a long-range transit planner.

Notably the system will secure forward thrust if a safe path cannot be discerned to await operator assessment.

The DriX Deployment System (DDS) is a cradle and docking system for deployment of DriX to and from a vessel. The DDS is similar to a large rigid-hulled-inflatable-boat (RHIB) having inflated sponsons, but with a protective top and the stern cut away, such that the DriX can be piloted into the stern and locked in place within the DDS. The DDS is designed for a dual-point pick, allowing modifications to be made to a standard ship's davit for deployment of the DDS (and DriX). Details of this operation are described in later sections.

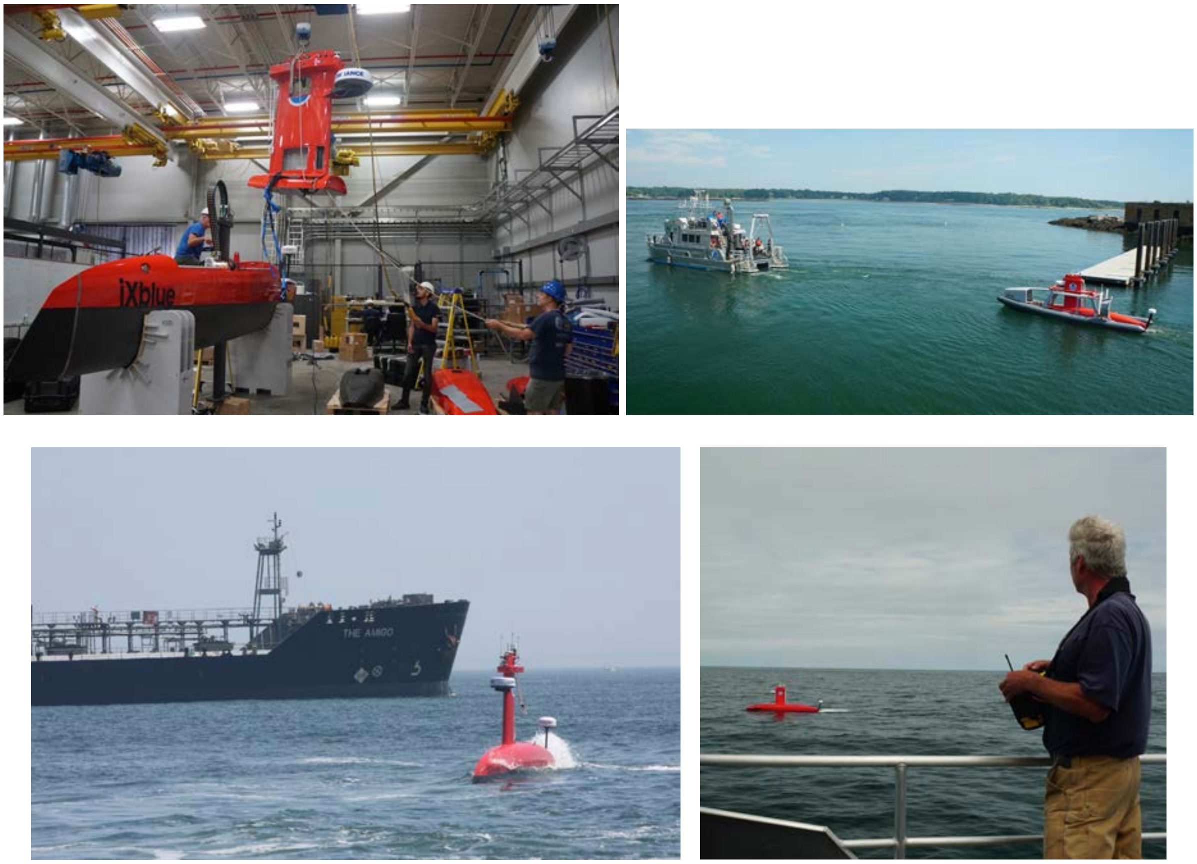
DriX 12 and its DDS at the UNH Pier Facility.

The DriX-12 gondola is equipped with a Kongsberg EM2040 multibeam echosounder (MBES) and EK-80 fisheries sonar operating at 38kHz, 70kHz, 120kHz and 200kHz. While the Processing Unit for the EM2040 is mounted within the DriX hull, the EK-80 Wide Band Acoustic Transceivers (WBAT) are mounted inside the gondola. This arrangement was selected to minimize the effect of EMI on these highly sensitive systems. To support sonar operations DriX-12 is also equipped with a CTD winch and Valeport CTD. This system allows operators to conduct CTD casts while the DriX is deployed to depths exceeding 150 m. A Windows "Survey PC" exists for operating sonar systems on board and a Network Attached Storage (NAS) with a 10 Gbps deck Ethernet connection, provides a central location for both storage and retrieval of sonar and vehicle logs.

DriX 12 Delivery and Acceptance

Sea acceptance was hosted at the University of New Hampshire's USV lab and marine facilities. Original plans would have provided ample time for vehicle assembly, followed by a full week for sea and sonar acceptance, and then two, week-long training sessions for 12 NOAA operators before demobilizing the system for shipment to a NOAA vessel. However, international shipping delays in excess of four weeks forced the assembly and acceptance into just five days, leaving the operator training to be rescheduled at a later date.

DriX-12 arrived at UNH on August 2nd, with the arrival of Exail personnel Aug 3rd, assembly began in earnest Aug 4th in collaboration with UNH. NOAA personnel arrived Aug 8thth. DriX-12 Commissioning and Sea Acceptance were conducted Aug 8-12 from the UNH Research Vessel Gulf Surveyor. Commissioning involves a systematic verification of proper operation of each sensor, system, and algorithm in the DriX.



Assembly of DriX-12 by Exail and UNH Team (upper left), DriX and DDS being towed by the UNH Reserch Vessel *Gulf Surveyor* for Commisioning and Sea Acceptance Testing (upper right). DriX-12 piloting tests, with Michael Gallagher operating (below).

DriX 12 and DDS aboard a 28”-deck-height trailer, and antennas removed to meet Department of Transportation road height requirements (total height approx. 10ft, 8”).

With Commissioning and Sea Acceptance completed, the DriX was loaded aboard a flat-bed trailer and transported to Cleveland, OH to meet NOAA Ship *Thomas Jefferson.*

DriX-12 Integration into NOAA Ship Thomas Jefferson

Shipboard integration began on August 27th. Custom cradles were designed by Exail to accommodate the DDS and DriX within the VEST davits aboard the *Thomas Jefferson*. These were manufactured by a NOAA contractor and installed by the ship’s crew just after DriX arrival on site in Clevelend. DriX was then craned into place to make final adjustments. The aft Iridum Certus antenna was removed due to its tight clearance with the ship’s rescue boat. Over-the-horizon operations were not intended in these initial operations.

DriX Cradle fitted to the VEST davits aboard the *Thomas Jefferson*.

Left, the aft cradle manufactured for the *Thomas Jefferson* is shown with the DDS and DriX suspended above it, looking forward. On the Right, the same cradle design, this time manufactured for the *Oscar Dyson* with markings to illustrate material that was subsequently removed to allow self-centering of the system.

The initial cradle design required a small modification worthy of mention. Along the opening of the bottom of the DDS into which the DriX fits is a rail that extends below the rest of the hull. This rail must be centered within the cradle allowing the central cradle cut-out to accommodate the additional material of the rail. Unfortunately, the cradle was not designed in a way such that the DDS would self-center into the necessary position, which required careful attention by operators to ensure the DDS was centered when landing the DDS during operations when underway. This design was improved in a subsequent installation aboard NOAA Ship *Oscar Dyson*, by removing the inner most pads and tapering the metal such that the DDS would more easily self-center into he supports. See Figure above.

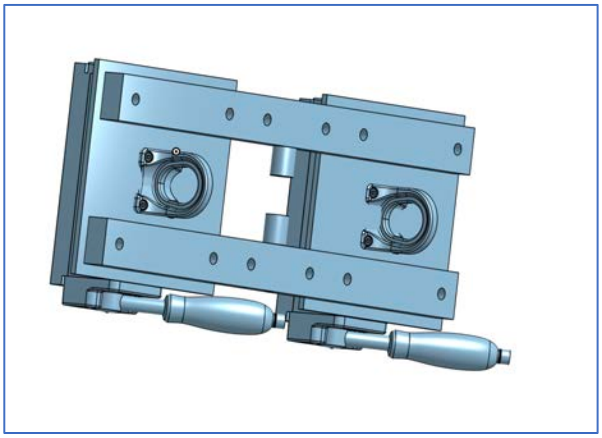
PAINTER BOOM

To keep the DDS and DriX away from the ship's hull during deployment and retrieval, they are towed from a painter boom mounted forward of the davit, extending athwartships. In 2019 during initial DriX trials, a temporary boom was manufactured by Exail (then iXblue) and clamped to the scuppers along the rail forward of the Davit. The boom is a carbon fiber spare, suspended by block-and-tackle fore, aft and above. The setup is shown in the figure below.

The painter boom installed forward of the Davit in 2019, and the preferred installation location marked in green.

In 2019, the boom's location was found to be too close to the DDS when a roll of the ship to port lifted the bow of the DDS from the end of the painter boom, ultimately breaking the hardware securing the painter line to its tip. A boom location forward of the existing location was desired and is shown in green in the image above. This location was chosen to balance the trade-offs of not being so far forward that the DDS could not be pulled away from the hull, not so low that its tip might be submerged in a wave, and not so high or far aft to cause vertical pulling on the DDS with a roll to port as before.

Restrictions associated with traversal of the Saint Lawrence Seaway and locks into and out of the Great Lakes prevented welding external to the ship's hull, so another solution was required. The mount was instead secured to the hull with industrial lift magnets. Two 725 lb. rare-earth lift magnets (Industrial Magnetics Model FXP712) were selected having a 3:1 design factor and designed for thin steel plates to achieve its maximum lift rating to match the ship's hull thickness (3/8 in). After derating the vertical pull rating for paint thickness (x1/2 at 16 mil) and shear loading (x1/4), the total holding capacity was expected to exceed 180 lbs, which was expected to be sufficient as long as the boom could be kept roughly orthogonal to the ship's hull. A field test after initial mounting verified this number, but a safety line was also installed. The preliminary and final designs can be seen in the figure below.



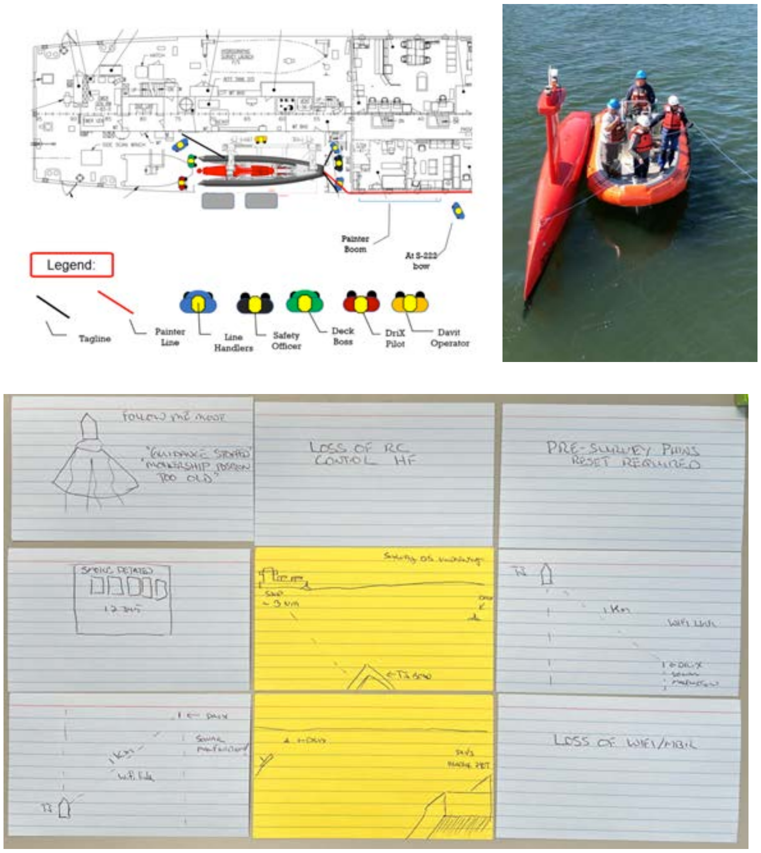
Preliminary design of the Painter Boom mount (top left), using two 725 lb industrial lift magnets, and its final design mounted to the hull (top right and below).The magnetically attached painter boom, used to ensure the DDS would tow away from the ship's hull when deployed by the davit.

OTHER PRE-UNDERWAY PREPARATIONS.

In addition to installation of DriX, the ship made many other pre-underway operations. A custom work platform was built by the ship's engineering team to provide safe access to the DriX and UDS while stowed in the davit (See Figure).

Work platform installed to provide safe access to the DDS and DriX-12 while in the davit.

Roles and responsibilities during deck operations were identified and practiced prior to deck walk-throughs and these were followed by practice operations over the side at the pier. The goals of these operations were to establish solicit input and ownership of the deck crew in developing safe, effective operating procedures and to practice until each step could be conducted in a smooth and timely way and was easily anticipated. These were documented for development into standard operating procedures by the ship for future operations. (See figure below).



Preparations prior to getting underway included developing a line handling and deck plan for over the side operations (upper left), dead boat recovery practice by a small-boat team (upper right), and cards used in scenario role play to practice radio communications between the Bridge and DriX Operators and for facilitation of discussion around DriX Casualties.

Prior experience in USV operations has shown that clear and concise communications between a Deck Officer and a USV operator is critical to successful and safe operations. However, Deck Officers and USV operators, who are several decks away, have different visual views of the situation (or perhaps none at all), might be working off different chart and radar displays, and may have very different technical understandings of the capability or constraints of the USV. These differences often result in confused, overly verbose communications that can cause delays when a timely response is warranted, and even be unsafe when they distract from other navigation duties. To improve communications between stations scenario-based roll play was conducted with Bridge Deck Officers, USV Operator and the Commanding Officer. Index cards illustrating some traffic situation, equipment malfunction or ship's casualty were provided in separate scenarios to an assigned role, who then practiced radio communications and proper responses to other participants. The group then could discuss the actions taken, critique and improve on the radio communications, establish common understanding in the technology and USV lingo, and allow the Commanding Officer to provide ship-wide guidance as necessary. For example, on the Commanding Officer's directive, each radio communication was prepended with “DriX is Safe” when the communication was informational, or “DriX is Standing into Danger” when the communication was to relay safety related information that required immediate action and attention.

Also, during the pre-underway operations practical aspects of Exail's DriX Supervisor Training were held for six NOAA personnel, including the ship's acting Chief Survey Technician, Chief Engineer, Chief Electronics Technician, a Junior NOAA Corps Officer and a representative from the Hydrographic Surveys Technology Branch. Participants were introduced to the major systems, their operation, and required maintenance. In addition, the training included a detailed hands-on walk though of the DriX electrical systems, teaching students to read the schematics and corresponding labeling on individual components. Students also helped in the setup of telemetry systems, operator workstations, and display.

DriX Supervisor Training evolutions aboard the *Thomas Jefferson.*

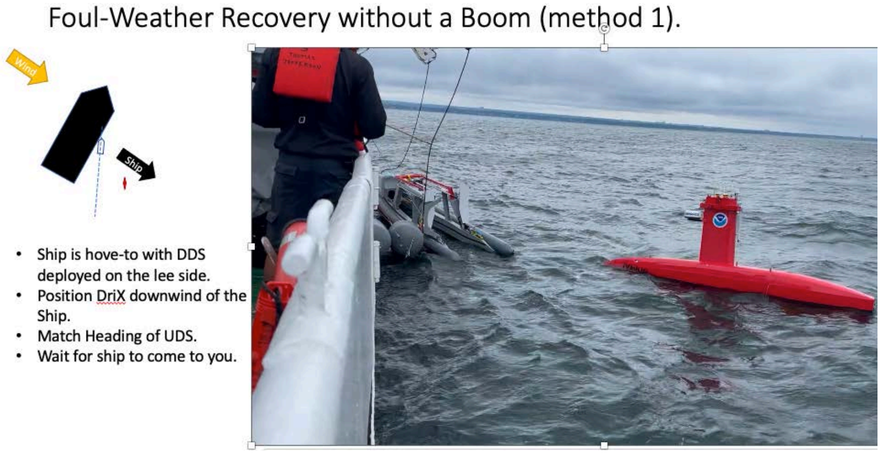
DriX Operations:

With DriX integration complete the ship got underay to begin a 9 day period of at-sea testing and training to prepare for two weeks of production survey operations beginning Sept 12. Critical to these operations were the practicing of deployment and recoveries at sea, dead-boat recovery, and piloting and mission planning experience for Supervisor Training attendees.

Foul weather and seas prevented deployment on some days and contributed to a mishap with the ship's temporary painter boom when pitching of the DDS after DriX deployment caused the boom to fold up against the ship and then slide slightly on the hull. The boom was secured to the ship and would have to be reset on return to port.

The crew of NOAA Ship *Thomas Jefferson* was undaunted and continued to deploy DriX, inventing new methods for deployment and recovery without the boom. In preparation for DriX operations the ship had procured two large 3 ft diameter fenders, which were used to fend the DDS when deployed with it's stern away from the ship's hull either with the ship stationary or making just a few knots. Recovery remained a challenge, and two methods were devised, one with the ship hove-to and the second underway.

In the first method the ship is oriented to make a lee on the recovery side, and the DDS is deployed with a large fender to hold the stern away from the ship's hull. Then rather than a direct approach by the DriX pilot, the DriX is stationed down wind of the ship on a heading to match the DDS and just astern of it. The DriX pilot then patiently holds station as the ship and DDS drift downwind towards it, docking the DriX into the DDS when the bow of the DriX passes in front of the stern opening of the DDS.


Foul-Weather Recovery without a Boom (method 1).

- Ship is hove-to with DDS deployed on the lee side.
- Position DriX downwind of the Ship.
- Match Heading of UDS.
- Wait for ship to come to you.

Method 1 of DriX recovery without a painter boom, in which the DriX is positioned in the lee of the stationary ship with the DDS deployed with fenders. The DriX pilot matches the heading of the DDS, and enters the DDS when the ship and DDS drift across its bow.

In Method 2 of DriX recovery without a painter boom, the ship remains underway at 2.5 knots, on an initial heading that places the wind and waves on bow to produce a lee on the recovery side (STBD in this case). The DDS is deployed over the side with fenders to maintain distance from the hull. The DriX pilot positions the DriX adjacent to the ship's stern. The ship then commences a slow turn to the recovery side, providing a lee and smooth water to the DDS and DriX. As the ship turns, line handlers slacken the painter lines, forward first and then aft. This progression allows the flow of water to catch the bow of the DDS, swinging it away from the hull of the ship and providing roughly two minutes during which time the DriX can be safely piloted inside, free and clear of the ship's hull.

Method 2 of DriX Recovery without a painter boom, in which the ship executes a slow turn to provide smooth clean water for the DriX during docking.

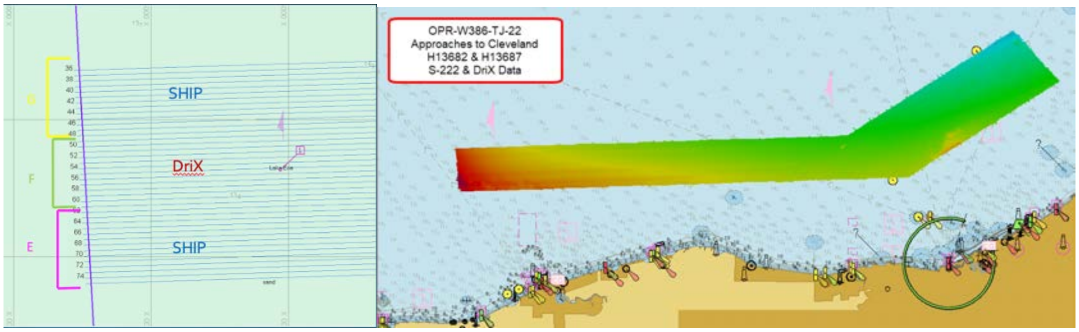
DRIX SURVEY OPERATIONS

From September 12 to September 30, the Ship and DriX conducted production survey operations in the approaches to the Port of Cleveland. DriX was deployed 11 of the 16 days, covering some 1146 linear nautical survey miles (LNM). DriX was not deployed in significant wave heights exceeding 1 m. The ship's ability to safely deploy a small workboat in the event of needing to manually recover the DriX proved to be the limiting factor.

The ship established a 48-hour cycle of operations, in which DriX was deployed at 0825 and recovered at 1600 the following day. Operational debriefs, data recovery, training and maintenance were performed overnight and the DriX was deployed the following day, again at 0825. With this operational schedule, DriX could survey continuously at 10 knots and retain a 30% fuel reserve before recovery. Watches consisted of a DriX Pilot and Survey Tech, augmented by an Exail contractor to provide guidance and feedback as the newly trained operators gained experience on operations. Watches were nominally 4 hours in length, with one 8-hour watch due to limited numbers of qualified watch-standers.

During the port call the ship's painter boom was reset with modifications to the placement of the magnetic mount that prevented further incident during the ensuring production survey efforts. All deployments and recoveries were conducted using the boom to tow the DDS at 4.5 knots. Although DriX is capable of lidar-based automated docking, DriX was manually piloted during these operations.

Survey lines were planned in Hypack for both the ship and DriX vehicle. The lines were then exported to "L84" format for import into the DriX HMI for execution. DriX automated "drive by coverage" was attempted but was abandoned for fixed line spacing after DriX failed to follow the expecte path. Shallow waters dictated just 30-50 m survey lines, so the DriX and ship operated in adjacent survey areas. Although the ship and DriX were operated independently, DriX was maintained within five nautical miles at all times to allow the bridge watch standers to aid the DriX Operator in navigating other vessel traffic if necessary and to maintain line of sight communications.



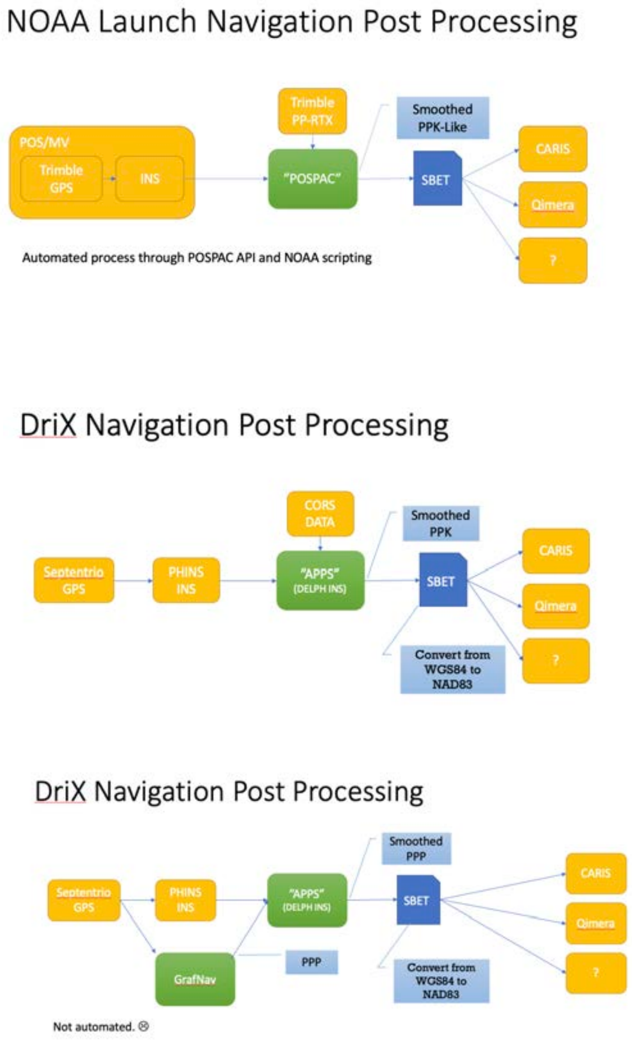
An example of survey area responsibilities for the ship and DriX (left) and data collected in the approaches to the Port of Cleveland (right)

During survey operations, DriX conducted CTD casts using it's onboard winch system and Valeport sensor package. These casts could be transferred to the Survey PC via Bluetooth during operations and applied immediately.

DATA COLLECTION AND PROCESSING

DriX-12 is equipped with a Kongsberg EM2040, identical to other NOAA launches. However, NOAA survey platforms utilize Seafloor Information System (SIS) 4, DriX utilizes SIS-5. While functionally similar the differences were sufficiently large enough to cause some confusion operationally as operators adjusted to the new look and layout.

A comparison of three data processing workflows, that of a standard NOAA launch, that of the DriX, and a modified to be described, is illustrated in the figure below. NOAA launches navigate with an Applanix POS/MV, whose data is post-processed using Trimble's "PP-RTX" correction service to produce a Precise Point Positioning (PPP) quality smoothed best estimated trajectory (SBET). Similarly, the DriX navigates with a PHINS+Septentrio system, whose data is post processed along with GPS observables from a local reference station to produce a Post Processed Kinematic (PPK) SBET. These workflows are illustrated in the two upper panels of the figure. Unfortunately, the most local CORS reference station to the survey area was not found to provide sufficiently reliable data. In addition, NOAA firewalls prevented the automated download of reference station data. These issues lead the survey team to seek an alternative solution, which was found by post-processing the DriX GPS data for a Precise Point Positioning solution using GrafNav (NovAtel Inc.) with downloaded corrections for ephemeris and clocks. The resulting corrected positions were then smoothed into the PHINS data to produce a final SBET in WGS-84, which then had to be converted to NAD-83 using a separate Python script.



A comparison of typical navigation postprocessing strategies between NOAA launches, DriX and the method used during these operations.

Being new to NOAA's operations, the DriX data processing workflow did not have the benefit of integration into Charlene, NOAA's toolset for automating the initial navigation and initial sonar processing steps. These tools have greatly increased the efficiency of NOAA's data workflow and the manual processing required of this yet-to-be-automated system was sometimes painful. However, NOAA tools were still used in reading SIS-5 KMALL data files, merging SBETS once created, and in later steps to evaluate data quality and surfaces.

Data collected by the DriX vehicle was found to be comparable in quality to other NOAA survey platforms and often better in rough weather. A quantitative comparison was made with data collection by the *Thomas Jefferson*, and a systematic 20 cm discrepancy was found. There was insufficient time to fully investigate this discrepancy.

CONCLUSIONS AND FUTURE WORK

The DriX-12 integration aboard NOAA Ship *Thomas Jefferson* while not without growing pains, was a great success. A comparison of typical survey operations from a NOAA launch and that of DriX-12 are shown in Table 1. While both systems survey at comparable speeds much of the advantage provided by DriX-12 results from the ability to operate over-night with rotating watches aboard the larger vessel. Overnight operations nearly doubled the coverage rate. This increased coverage rate, when combined with the lighter and more efficient hull shape of the DriX provides a per linear nautical mile fuel efficiency of approximately 14% of that of the Launch.

Table 1

	NOAA Launch	DriX-12
Operation Cycle:	8/24 Hrs (33% of the day)	36/48 Hrs (75% of the day)
Avg. Coverage Rate:	1.7 LNM/Hr (40 LNM/Deployment)	3.75 LNM/Hr (180 LNM/Deployment)
Fuel:	50 Gal/Deployment (1.25 Liters/LNM)	32 Gal/Deployment (0.17 Liters/LNM)
Deployment Conditions:	SWH of 1.5-2m	SWH 1m [Rescue Boat Limited]
Deployments Per 48 Hrs:	2	1
Operators:	2-3	1 Operator + 1 Readily Available. In 4-6 Hr Shifts (Min. 4 Total)

Weather and sea state remain limiting factors in safe deployment and recovery of any uncrewed system. For the DriX vehicle aboard the *Thomas Jefferson*, it is ability to safely deploy of a crewed vessel to recover the DriX in the event of a malfunction, that currently limits operations. Possible factors that might mitigate these restrictions are facilities and personnel available to deploy from shore if necessary to aid a larger ship in the event of a UxS malfunction that prevents an easy or safe recovery (I.e. keel is stuck in down position, or future ship builds that might better equipped to safely deploy a rescue a crewed rescue boat. In addition, shipboard facilities that provide a weather protected area for DriX maintenance are essential.

Although data was collected to evaluate the capability of the auto-docking algorithm to successfully dock the DriX adjacent to the ship, only one attempt was made and it was unsuccessful. Operators decided to manually dock DriX for the remainder of the cruise. Experience on other vessels has shown that the DriX autodocking algorithm, when successful, is generally less likely to result in damage to the vehicle and should be pursued in future operations.

There were many challenges to data processing of DriX data within NOAA’s typical methods. Insufficient time was afforded to develop navigation post-processing strategies that might have improved the reliability of PPK processing with the PHINS. Although automated or batched processing is possible with the “APPS” post-processing package for PHINS data, there was insufficient time to integrate these methods into NOAA’s existing automated processes. Further, APPs was unable to export the final SBET in NAD-83, and required conversion in yet another step. [A feature request has been submitted for support of other common coordinate reference systems.] A known issue with Caris prevents successful integration of post-processed navigation data that has been logged over the GPS week. To avoid this, NOAA Launches break survey operations for 10 minutes at turnover of the GPS week, but continuous overnight operations with DriX-12 lead to an oversite for this need and one line was unable to be processed. Future operations should set aside time to work through these issues to ensure the efficiency of DriX operations can be fully realized.

Acknowledgements:

The authors would like to gratefully acknowledge the support and effort of the Captain and Crew of the Research Vessel *Gulf Surveyor* and that of NOAA Ship *Thomas Jefferson,* Don Jones, of, NOAA, and Research Engineers Andy McLeod and Avery Muñoz at UNH. This work was supported in part by NOAA Grants NA20NOS4000196 and NA19OAR4320072.